Global at-sea fish processing

A review of current practice, and estimates of the potential volume of by-products and their nutritional contribution from at-sea processing operations

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FRIENDS of OCEAN ACTION

Summary

Seafood consumption has a key role in global protein intake and broader human nutritional needs. This is directly, through consumption of seafood products, and indirectly, through its use in the animal feed chain to help produce additional food sources. However, 30% to 35% of the fish caught is either lost or wasted along the supply chain (FAO, 2020). A proportion of this includes losses through at-sea processing of fish and shellfish.

Global catch of fish and shellfish is 108 million tonnes (live weight). For the purposes of this report, the primary species groups identified as most likely to be processed at sea are demersal species, pelagic species (tunas, bonitos and billfish), and shellfish (squid). It is also assumed that the majority of other pelagic and shellfish species are less likely to be processed at sea (albeit there are exceptions).

Numerous species of fish and shellfish will undergo some form of processing (product transformation) at sea. This can be undertaken by varied sizes and types of fishing vessel, using an array of fishing gears to target the catch. There are variations on all these practices within countries, regions and globally. Data on all these areas are limited and it is only possible to provide general indications.

Vessels >24 m length overall (LOA) are most likely to be engaged in some degree of processing-at-sea operations. There are almost 68,000 vessels globally >24 m LOA. The majority (nearly 80%) of these are registered in flag states in Asia. The lack of data means it is challenging to provide any exact figures for these 68,000 vessels to show types of on-board processing facilities, extent of processing, exact weight of capture etc.

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Diverse types of fishing gear will be used by vessels undertaking processing at sea. The most typical gear types include trawls, longline, purse seine, and jiggers (squid).

Published data on the global production of by-products produced at sea is not available, therefore estimates based on global catch and by-product yields are provided in this report. Applying a series of assumptions and ranges provides a very broad estimate of by-products at sea. This is calculated as 1.5 to 25 million tonnes, globally. This huge range in quantities takes into account the lack of data and evidence, the fact that not all species are processed at sea, and that the extent of processing at sea varies within a species, in a country, between countries and globally.

The extent and type of processing is driven by several factors. Quality and hygiene requires guts (viscera) to be removed from demersal fish, to maximise shelf life. Market requirements for products are key drivers, for example frozen-at-sea products such as headed and gutted fish or fillets are produced to satisfy specific on-shore market requirements.

“A very broad estimate of by-products at sea is calculated as 1.5 to 25 million tonnes, globally.”

Larger 'factory' vessels, with fully automated processing lines on board, are more likely to retain by-products. By-products are retained for various reasons including direct human consumption markets (e.g. cheeks), further processing (e.g. skins for collagen), or introduction into the marine ingredients supply chain (fishmeal and fish oil). All of these are vital outlets for by-products.

There are numerous reasons why more by-products are not retained on board. They include lack of space/capacity on the vessels, lack of time to process, no/low demand, and low market value. It will take a significant shift in the market and value of by-products to change this current situation.

There are major vessels, types of vessels and nations that have become very successful at maximising the use of the catch. In these examples, vessels processing and freezing at sea retain a considerable quantity of by-products for different uses. Iceland has spent 30 years investing and innovating in by-products and, through collaboration, is able to maximise the use of a valuable species (cod). In the past 20 years, the Alaska pollock sector in the US has shifted attention from 'maximise volume of catch' to 'maximise utilisation of catch'. Catcher-processing-freezer vessels can now demonstrate full catch utilisation, with investment in on-board processing equipment and fishmeal production.

While there would be advantages to accessing and utilising more at-sea by-products, for both direct consumption and indirect consumption, this cannot be looked at in isolation. Other factors that should be taken into consideration include the impact on marine habitats and the ecosystem, implications for the crew (work, earnings, safety), catch handling/safety/storage, vessel infrastructure etc. This is before consideration of access to sustained outlets or markets that will suitably recompense fishers.

There are data and knowledge gaps to address in considering the potential for increased utilisation of global at-sea by-products. It is evident there are differences between species, vessels and flag states and this is not a 'one size fits all' challenge. However, with collaboration and investment in technology, infrastructure and markets, access to at-sea by-products could provide a way to maximise the use and value of the global catch of fish and shellfish.

Contents

1. Introduction, definitions, and context

The responsible production of food is vital to nourish the world's population. In addition, ensuring efficiency in food systems is critical to ensure the maximum nutrition is derived from the food we produce.

Food loss and waste is an issue of global concern. The 2030 Agenda for Sustainable Development reflects the increased global awareness of the problem. Target 12 of the United Nations' Sustainable Development Goals (United Nations, 2022) calls for sustainable consumption and production patterns, which includes maximising the use of food sources.

Seafood is an extremely valuable commodity, and it is vital to maximise the use of the global wild catch and aquaculture production. Seafood consumption plays an important role in global protein intake and broader human nutritional needs. This is directly, through consumption of seafood products, and indirectly, through its use in the animal feed chain to help produce additional food sources.

However, 30% to 35% of the fish caught is either lost or wasted along the supply chain (FAO, 2020). A proportion of this includes losses through at-sea processing of fish and shellfish. The volume of material that is removed from processing fish at sea could be a vital source of nutrition if it is possible to bring it ashore for utilisation.

This report aims to:

- Provide an overview of processing of seafood at sea to understanding current levels of loss (volume and nutrition).
- Better understand by-products that are retained and utilised by some vessels.
- Summarise the challenges for greater by-product retention, including identifying current knowledge gaps.

1.1. Understanding seafood processing at sea and by-products

After capture, some species of fish and shellfish may undergo some form of processing (product transformation) at sea. The extent of any processing at sea varies depending on the species, product format, market requirements (local, national, global), size of fish, value of by-products, availability of markets for by-products, on-board facilities, vessel sophistication etc.

The main activities that comprise processing at sea are detailed in Table 1.

Table 1: Potential extent of processing at sea

Processing activities	Components removed
Evisceration (gutting)	Removal of viscera, including liver and reproductive organs
De-heading	Removal of the head
Skinning	Removal of the skin
Filleting (or portion creation)	Production of the main part of edible flesh in a preferred format (e.g. fillet, block, steak)
Trimming (cutting fins and belly flaps)	Typically in conjunction with filleting, for trimming semi or wholly processed products
Gill removal	Gills
Shellfish processing (typically only for crustaceans and cephalopods)	Can include removal of heads, claws, evisceration. Peeling and cooking e.g. prawns may also be undertaken
Freezing	Technically classed as processing, does not in itself create by-products but can alter net weight of landed product e.g. drip loss on thawing

Table 2: Fish and shellfish by-products

Finfish		Shellfish (crustacea, cephalopods)
Guts	Fins	Heads
Livers	Scales	Shell
Heads	Lugs (pectoral fin and bone)	Viscera
Cheeks	Belly flaps	Legs
Tails	Frames (backbone)	
Skin	Others (e.g. blood, roe, milt)	

1.2. Understanding by-products from seafood processing

For the purposes of this report, at-sea by-products are defined as:

- the residual parts of fish and shellfish remaining after removal or separation of the main edible portion, and
- removed from the whole animal at sea.

Table 2 provides a list of by-products from fish and shellfish.

What constitutes a by-product varies depending on many factors; a by-product in one region may be a product for direct human consumption in another region, e.g. fish heads.

The term by-product does have alternative terminology depending on the region, the species and the point in the supply chain. For example, other terms include processing waste, rest raw material, co-products, offal, and trimmings.

For this report, the definition of by-products excludes by-catch, i.e. unwanted or unintended catch.

1.3. Understanding fishing vessels

Fishing vessels can be broadly classed into three categories: (MarineInsight, 2022)

- Commercial fishing vessels
- Artisanal fishing vessels
- Recreational fishing vessels.

This report is only concerned with commercial fishing vessels, used for catching fish and other seafood from wild fisheries for commercial profit.

Two size descriptors for fishing vessels are commonly used:

- Length overall (LOA) – the maximum length of a vessel's hull measured parallel to the waterline.
- Gross tonnage (GT) – the volumetric area of the hull up to the freeboard deck, plus shelter structures and the wheelhouse.

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These measures can provide an indication of potential on-board facilities, such as processing activities. However they cannot be used to accurately determine the nature of on-board processing, the extent of processing at sea or weight of landings.

Fishing vessels, of varying sizes, have differing levels of sophistication and on-board facilities. For ease, these are grouped into three size ranges:

- *Large vessels (>35 m LOA)* are likely to have some on-board processing facilities capable of producing a range of products, such as fillets, headed and gutted fish, or cooked and peeled shellfish. They are typically highly mechanised, with on-board freezing capacity. Fishing trip lengths would likely extend to weeks.
- *Smaller vessels (<24 m LOA)* are catching fish/shellfish which may or may not be processed at sea. However, processing operations would typically be manual, including gutting, possibly heading for some species, and tailing/declawing crustacea. Vessels of this size would be at sea for 0.5 to 10 days. While many vessels would have on-board refrigeration or other means of chilling the catch, smaller-sized (<10 m LOA) single crewed vessels would be less likely to have these facilities on board.
- *Fishing vessels (>25 m and <35 m LOA)* could theoretically cover either type of operation.

Fishing vessels are registered to a state/country and are required by law to carry the flag of that state and also follow the rules and regulations enforced by the same.

This is commonly referred to as the 'flag state'. For a country to be included in the list of flag states, it must adhere to all the norms and regulations established by the International Maritime Organisation (IMO). The practice of registering a vessel to a nation different than that of the vessel owner is known as the flag of convenience (FOC).

Data relating to the registration of fishing vessels will refer to the flag state. Although fishing vessels can typically land their catch in any port in any country (subject to official approval), fish landings data will refer back to the flag state but include landings in domestic ports and abroad (OECD, 2022).

1.4. Fishing gear types

There are a myriad of types of fishing gear, internationally classified into main groups and sub-groups (see Appendix). The table below includes a summary of the main categories and a brief description.

Within each main category of fishing gear there are numerous sub-categories, providing an indication of the variation in fishing gears that may be used globally.

Not all fishing gears are used in every major region. Legislative requirements for managing fisheries, fish stocks and fishing grounds will govern the use and type of fishing gear. The type of gear will be tailored according to the target species, fishing ground, fishing depth etc. Other variations will include, for example, modifications with selectivity devices.

The fishing vessel will be designed/developed to suit the method of fishing. For example, higher-powered vessels are needed for towed gears. Fishing vessels can also be licensed to use more than one type of fishing gear, to enable them to target different species at different times, for example in different fishing seasons.

Table 3: Main categories of fishing gear (He, 2021)

Main category of fishing gear	Description
Surrounding nets	A surrounding net is a long piece of net that is constructed mostly from rectangular sections of netting framed by ropes and catches fish by surrounding a school of fish.
Seine nets	Seine nets can be cone-shaped nets with long wings and a codend, or a long piece of net without a codend, catching fish by encircling and herding.
Trawls	The trawl is a cone-shaped body of netting, usually with one codend, towed behind one or two boats to catch fish through herding and sieving.
Dredges	A dredge is a cage-like structure often equipped with a scraper blade or teeth on its lower part, either pulled or towed to dig animals out of substrate and lift them into the cage or bag.
Lift nets	A lift net is a piece of netting mounted onto a frame that is lowered into the water to allow fish to enter the area above the net and is then lifted or hauled upward to collect the fish accumulated there.
Falling gear	Falling gear is a net or a basket-like structure which is cast, pushed down, or allowed to fall from above to catch fish underneath it
Gillnets and entangling nets	Gillnets and entangling nets are long rectangular walls of netting that catch fish by gilling, wedging, snagging, entangling or entrapping them in pockets.
Traps	Traps are stationary structures of many shapes and sizes into which fish are guided, or pushed by the current, or drawn into the gear by bait or other attractants.
Hooks and lines	Hook-and-line gears are those that use hooks (including jigs) and lines to catch fish.
Miscellaneous gear	Miscellaneous gears include all other gears not included in other categories. There are a variety of other gears in world fisheries, especially in small-scale and artisanal fisheries. Include harpoons, rakes etc.

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2. Methodology

In order to identify the extent of processing seafood at sea, the types of vessels used and which flag states they are registered to, two main research areas were undertaken: desk-based research and questionnaires/interviews with key stakeholders.

The project commenced in late January 2022, with a completion date of 10 March 2022.

2.1. Desk-based research

The main elements of the desk-based research focused on:

- Fishery and vessel data i.e. global and regional catch data, processing at sea, fishing vessels
- Fish product/by-product yields
- Nutritional composition of by-products.

2.1.1 Fishery and vessel data

Between 24 January and 4 February 2022, online searches were undertaken using Google. Search terms included combinations of the following:

- Demersal/pelagic/whitefish/squid
- Global production/capture statistics
- World capture landings
- Processing at sea/fishing/fishing vessels.

All fishery data used is publicly available, with fish landings data derived from global sources (Food and Agriculture Organization of the United Nations, 2022). A copy of the full dataset was obtained from the individual tables and reconstructed into a relational database. This facilitated analysis of the catch data with other factors such as by-product yields.

All catch data is presented in live weight/live weight equivalent, unless otherwise stated.

Global records/lists of fishing vessels were identified through the online searches. These were supplemented by additional online searches for fishing vessels by size, type, flag state, and any information on processing at sea.

2.1.2 By-product yields

Between 24 January and 4 February 2022, online searches were undertaken using Google and Google Scholar.

Search terms included combinations of the following terms:

- Fish/shellfish (groups of species-specific names including cod, pollack, tuna and squid were also used)
- Edible portion/yield/processing yield
- By-product portion/yield.

All the data used is publicly available.

2.1.3 Nutritional data

Between 24 January and 9 February 2022, online searches were undertaken using Google and Google Scholar. Search terms included combinations of the following terms:

- Fish/shellfish (groups of species-specific names including cod, pollack, tuna and squid were also used)
- By-products/waste
- Nutritional value/proximate analysis/composition/benefits/minerals.

The authors had access to relevant data from previous research projects that had been published.
All the data is from publicly available sources.

2.2. Questionnaires and interviews

To elicit commercial knowledge from different regions, two questionnaires were devised.

The first questionnaire was detailed and included a series of questions to understand current practices (see Appendix).

This initial questionnaire was distributed to a series of industry stakeholders between 1 and 8 February 2022. Closing dates were up to 15 February (see Appendix).

A shorter and simpler questionnaire was produced online (Google Forms) and issued on LinkedIn with open access on 8 February 2022. The closing date was 18 February 2022 (see Appendix).

A limited number of interviews were conducted only for the purposes of developing case studies (Table 3).

With the limited responses available, the results are used for context in various sections of the report. Responses to the questionnaires are collated and summarised in the Appendix.

Table 3: Summary of responses to questionnaires and interviews

	Distribution method	Responses received
Questionnaire 1 - detailed	Direct to 30 stakeholders	6
Questionnaire 2 - simple	Via LinkedIn (unknown number) and direct (10)	2
Interviews	Online discussions	2

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3. Global catch and fishing fleets

Before considering processing at sea it is essential to understand the global catch – i.e. capture of fish and shellfish – and the global fishing fleet.

3.1. Global catch

The Food and Agriculture Organization estimates of wild-caught species, based on 2019 catch data (FAO, 2020), were: 108 million tonnes (live weight), comprising:

- 40 million tonnes 'demersal fish' species
- 30 million tonnes 'pelagic' fish species
- 38 million tonnes 'shellfish' fish species.

For the purposes of this report, the primary species groups of relevance are demersal species, pelagic species (tunas, bonitos and billfish), and shellfish (squid). This is based on the assumption that the majority of other pelagic and shellfish species are less likely to be processed at sea. While there are exceptions to this (e.g. pelagic freezer trawlers), with limited evidence available it is a reasonable assumption.

Table 4 describes catch production of the main species groups of primary relevance to this report. These species groups are based on the FAO 'International Standard Statistical Classification for Aquatic Animals and Plants' (ISSCAAP) code system. The ISSCAAP codes are assigned by FAO, which divides commercial species into 50 groups on the basis of their taxonomic, ecological and economic characteristics. The ISSCAAP coding system provides a useful overview of global catch in terms of commercial species/groupings.

The ISSCAAP species groups are used for the remainder of the report.

Key findings

- The combined weight of the groupings 'Cods, hakes, haddocks', 'Flounders, halibuts, soles', 'Tunas, bonitos, billfishes' and 'Squids' comprises 49% of the catch production, for the species groups of primary relevance.
- After 'Marine fish – not identified', the greatest weight captured is represented by the group 'Cods, hakes, haddocks' (21.7% of catch production, for the species groups of primary relevance).

3.2 Regional catch data (continents)

Global catch is presented on a regional basis to show the geographical variation in tonnage (tonnes) captured.

The table below (Table 5) describes global catch in terms of ISSCAAP categories/species according to the FAO continental designations.

Table 4: Global catch production of the species groups of relevance to this report, based on ISSCAAP groupings (2019)

Species grouping (based on where they typically reside in the water column)	ISSCAAP Group/Species.	Catch Production (millions of tonnes, live weight)
Mixed demersal / pelagic	Marine fish - not identified	10.5
Demersal	Cods, hakes and haddocks	9.3
Pelagic	Tuna, Bonitos and billfish	8.1
Mixed demersal / pelagic	Marine coastal fisheries	7.5
Demersal	Miscellaneous demersal fish	2.8
Shellfish	Squids	2.8
Demersal	Flounder halibut and Soles	1
Mixed demersal / pelagic	Sharks, rays and Chimera	0.8
	Total	**42.8**

Table 5: Global catch of key species groups by region / continent

Geographical regions / continent	ISSCAAP Categories / Species, tonnes captured (millions of tonnes)							
	Cods haddock hakes	Flounder halibut soles	Miscellaneous demersal	Tuna Bonitos Billfish	Marine Fish not identified	Miscellaneous coastal fisheries	Squids	Sharks rays and Chimera
Europe	5.70	0.36	0.40	0.55	0.05	0.39	0.15	0.12
Americas	2.83	0.35	0.24	1.30	0.06	0.63	0.09	0.16
Asia	0.33	0.17	1.93	4.98	9.39	5.60	1.75	0.29
Africa	0.31	0.09	0.13	0.46	0.67	0.88	0.08	0.10
Oceana	0.17	0.00	0.11	0.87	0.06	0.04	0.00	0.03

Key findings

- The majority of the 'Cods, hakes, haddocks' and the 'Flounders, halibuts, soles' are captured within Europe and the Americas.
- 'Tunas, bonitos, billfishes' are caught mainly in the Americas, Asia and Oceana.
- Asia accounts for the majority of fish captured within the categories 'Miscellaneous demersal' and 'Marine fish not identified'.

3.3 Catch data for key species, by main countries (flag state)

Within the ISSCAAP species groups, the majority of the global catch is dominated by a few key species and is targeted by a relatively small number of countries.

Table 6 shows the total tonnage (tonnes) captured for the top 15 species, together with the main countries that target each species.

Table 6: Total weight of key species caught by country (flag state)

Species (in order of catch weight of catch)	Total catch (millions of tonnes)	Main countries / flag state capturing species (in order of weight of catch by country)	
Alaskan Pollock	3.40	1. Russian Federation 2. United States of America	3. Japan 4. Canada
Skipjack tuna	3.23	1. Indonesia 2. Korea, Republic of 3. Philippines 4. Ecuador 5. Taiwan Province of China 6. Japan 7. Papua New Guinea	8. Kiribati 9. United States of America 10. Spain 11. Micronesia, Fed. States of 12. Maldives 13. Viet Nam 14. Seychelles
Yellowfin Tuna	1.56	1. Indonesia 2. Mexico 3. Philippines 4. Papua New Guinea 5. Japan 6. Spain 7. Taiwan Province of China 8. Iran (Islamic Rep. of)	9. Korea, Republic of (South Korea) 10. Ecuador 11. France 12. Sri Lanka 13. Maldives 14. United States of America 15. Seychelles
Atlantic cod	1.22	1. Norway 2. Russian Federation 3. Iceland 4. Faroe Islands 5. Greenland 6. United Kingdom 7. Spain 8. Germany	9. Denmark 10. Canada 11. Portugal 12. France 13. Poland 14. Sweden 15. Estonia
Largehead hairtail	1.13	1. China 2. Iran (Islamic Rep. of) 3. Korea, Republic of 4. Taiwan Province of China 5. Malaysia 6. Pakistan 7. Angola 8. Morocco	9. Japan 10. Thailand 11. Senegal 12. Venezuela, Boliv Rep of 13. Ghana 14. Nigeria 15. Congo
Croakers, drums nei (multiple species)	0.65	1. China 2. India 3. Indonesia 4. Malaysia 5. Ecuador 6. Pakistan 7. Nigeria 8. Korea, Republic of (South Korea)	9. Oman 10. Thailand 11. Guinea 12. Peru 13. China, Hong Kong SAR 14. Iran (Islamic Rep. of) 15. Congo, Dem. Rep. of the
Threadfin breams nei (multi species)	0.58	1. China 2. Indonesia 3. Malaysia 4. Philippines 5. Thailand 6. China, Hong Kong SAR 7. Pakistan	8. Tanzania, United Rep. of 9. Egypt 10. Eritrea 11. Brunei Darussalam 12. Kuwait 13. Singapore
Argentine hake	0.45	1. Argentina 2. Spain 3. Uruguay 4. Korea, Republic of (South Korea)	5. Falkland Is.(Malvinas) 6. Brazil 7. United Kingdom

3. Global catch and fishing fleets

Table 6: Total weight of key species caught by country (flag state)

Species (in order of catch weight of catch)	Total catch (millions of tonnes)	Main countries / flag state capturing species (in order of weight of catch by country)	
Pacific cod	0.43	1. United States of America 2. Russian Federation 3. Japan	4. Korea, Republic of 5. Canada
Tuna-like fishes nei (multiple species)	0.42	1. Viet Nam 2. China 3. Korea, Republic of (South Korea) 4. Pakistan 5. Zanzibar 6. Oman 7. Ecuador 8. Sierra Leone	9. Mauritania 10. Costa Rica 11. Georgia 12. Canada 13. Japan 14. Cameroon 15. Trinidad and Tobago

Nei = not elsewhere identified

Key findings

- A relatively small number of countries (flag states) are responsible for the majority of landings of species most likely to be processed at sea (to some extent).

3.4 Utilisation of global catch

Based on 2018 catch data (FAO, 2020), of the total tonnes of fish produced in world fisheries and aquaculture:

- 88% (over 156 million tonnes) of total fish production was used for direct human consumption
- 12% (22 million tonnes) was used for non-food purposes.

Of the 22 million tonnes for non-food purposes:

- 80% (~18 million tonnes) was reduced to fishmeal and fish oil
- 20% (4 million tonnes) was used:
- As ornamental fish
- For culture (e.g. fry, fingerlings or small adults for on-growing)
- As bait
- In pharmaceutical uses
- For pet food
- As raw material for direct feeding in aquaculture and for the raising of livestock and fur animals.

The share of fish production destined for human consumption is expected to continue to grow, reaching 89% by 2030. In per capita terms, world fish consumption is projected to reach 21.5 kg in 2030, up from 20.5 kg in 2018.

3.4.1 Global levels of loss and wastage

A large proportion of fisheries and aquaculture production is either lost or wasted; about 35% of the global harvest (FAO, 2020).

The main causes for these losses are inefficiencies in value chains and inadequate infrastructure, services and practices (Table 7).

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Table 7: Areas for further development to tackle catch/harvest loss or wastage

Business level developments	Country / regional developments	Usage / consumption
• Logistics • Potable water • Ice • Cold storage • Refrigerated transport. • Skills	• Appropriate policies • Regulatory frameworks • Capacity building • Services e.g. power, water • Infrastructure e.g. roads	• Total catch utilisation (food, feed) • Access to markets (food, feed) • Consumer know-how (reduce consumer waste, alternative products)

3.5 Global fishing fleet and fishing vessels

In 2018, the total global number of fishing vessels was estimated to be 4.56 million (FAO, 2020).

In the same year:

- The number of motorised fishing vessels totalled 2.67 million.
- Over 80% of motorised fishing vessels in each major region were <10m LOA. In Africa, Asia and Oceania this figure was closer to 90%.
- There were almost 68,000 fishing vessels with an LOA of at least 24 m. This was approximately 3% of all motorised fishing vessels.

3.5.1 Global fishing fleet and vessel size profiles

Data on the global number of fishing vessels and the extent of on-board processing was not identified during the research phase of the project. As such, assumptions have been made and estimates have been produced. Regarding the size of vessels and extent of on-board processing, general assumptions can be used (Blackhurst pers. comms.):

- Vessels <10 m LOA are less likely to undertake significant processing at sea beyond basic catch sorting, washing and possibly some gutting (finfish).
- Vessels 10 m to 24 m LOA may undertake some processing, but likely just catch sorting, washing and gutting (finfish).
- Vessels >24 m LOA are more likely to be processing at sea (to varying degrees).

FAO provides general data on fishing vessels >24 m LOA (Figure 1). It is evident that these are a small proportion of the global fishing fleet.

Using these figures and the estimates of the global fleet, it is possible to calculate the potential number of fishing vessels >24 m LOA in each continent (Table 8) (see Appendix for further information). This is the most basic way to provide an estimate of the fishing vessels engaged in processing-at-sea operations. The list of continents is useful as a broader overview due to the lack of data available for all flag states.

Figure 1: Size distribution of motorised fishing vessels by region (2018) (FAO, 2020)

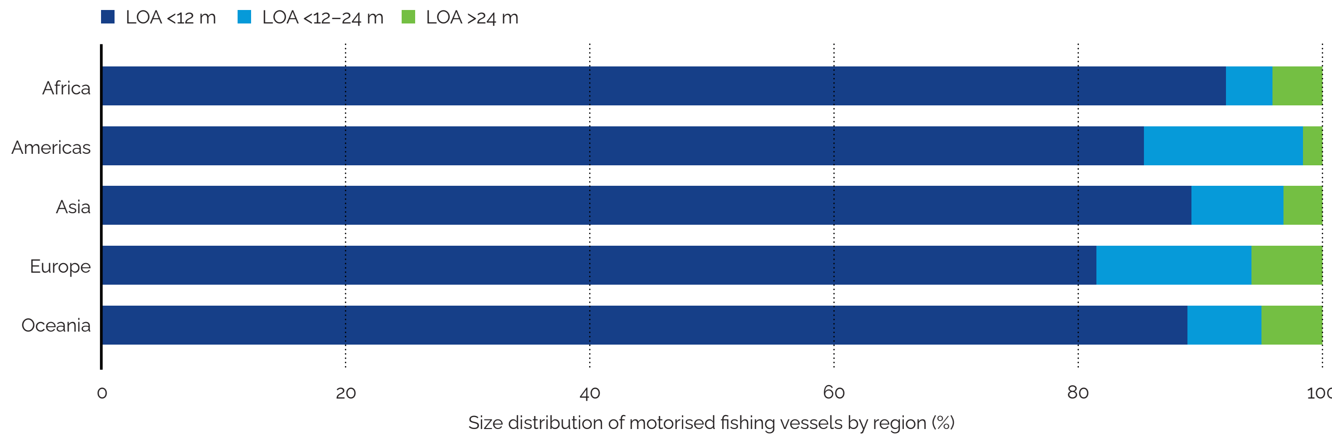

Table 8: Estimated number of fishing vessels >24m LOA, by major region/continent (and most likely to be engaged in some degree of processing at sea)

	Fishing vessels >24m LOA % of own fleet*	Estimated % of global motorised fleet**	Estimated total number of vessels >24m LOA***
Africa	4.1	10.6	7,213
Americas	1.7	5.8	3,954
Asia	3.2	79.2	53,726
Europe	5.8	4.1	2,810
Oceania	4.9	0.2	129

*based on (FAO, 2020)
** calculated using total for each continent as a proportion of global motorised fishing vessels (Food and Agriculture Organisation, 2021)
*** calculated using FAO total of 67,800 fishing vessels >24 LOA

3. Global catch and fishing fleets

Linking different data on fishing vessels >24 m LOA can be challenging; however, the information in Table 8 was also cross-referenced with data on the use of automatic identification systems (AIS) (Taconet, 2019). This data includes a list of the top 20 countries where fishing vessels >24 m LOA use AIS (see list below). First on the list, with two-thirds of the world's fishing vessels larger than 24 m, is China.

1. China
2. Japan
3. Indonesia
4. Papua New Guinea
5. Republic of Korea
6. Argentina
7. USA
8. Italy
9. Russia
10. Peru
11. Malaysia
12. Venezuela
13. Taiwan Province of China
14. Norway
15. Myanmar
16. Morocco
17. Thailand
18. Mexico
19. Spain
20. Tunisia

Cross-referencing these figures with an incomplete dataset on fishing vessels grouped by LOA (OECD, 2022) provides an estimate of the number of vessels overall in each size category (Table 9). Unfortunately, this dataset only includes 32 countries/nations as members of the OECD, meaning the figures are underestimated.

However, this data is further broken down by smaller size ranges and by country (see Appendix), and is useful as an indication for specific countries.

3.5.2 Types of fishing gear used by vessels undertaking processing at sea

The profile of commercial fishing gear used by vessels >24 m LOA varies greatly. Based on the information available, a summary of the main types of fishing gear used for the species of main commercial interest is provided (Table 10).

Key findings

- Vessels >24 m LOA are most likely to be engaged in some processing-at-sea operations.
- There are almost 68,000 vessels globally >24 m LOA. The majority of these (nearly 80%) are registered in flag states in Asia.
- The lack of data means it is challenging to provide exact figures for these 68,000 vessels including types of on-board processing facilities, extent of processing, exact weight of capture etc.
- Based on the key species, various types of fishing gear will be used by vessels undertaking processing at sea. Most typical gear types would include trawls, longline, purse seine, and jiggers (squid).

KNOWLEDGE GAPS

- The number of vessels and extent of processing facilities on board
- The extent of processing undertaken by fishing vessels, based on vessel size range

Table 9: Vessel size profiles by country in 2018 (not all countries are represented in the dataset)

	Unidentified LOA	<25m LOA	>25m LOA
All regions	1,633,881	248,354	5,848

Table 10: The various gear types most likely to be used by vessels >24m LOA used to target the main species /groups of interest to this report

Species	Demersal/ beam trawl	Otter trawl	Gillnet and pound nets	Hook and line handline	Longline	Pair trawling Pole and line Hook and han-dline Purse seine Trolling
Cod	x		x			
Pollock		x				
Haddock	x					
Hakes	x		x		x	
Flounder (plaice etc)	x	x				
Halibut	x				x	
Soles	x		x			
Tunas			x	x		x
Squid						x

4. Processing at sea: by-product yields and current practice

Published data on the global production of by-products produced at sea was not identified. Therefore, estimates based on global catch and by-product yields are provided. It is impossible to determine with any accuracy the extent of processing at sea, and thus the by-products generated. As such, all figures should be classed as indicative only.

Current practices show a significant variation between regions, extent of processing of the same species and different species etc. The majority of published catch data is converted to 'live weight equivalent' in order to standardise reporting volumes. It was outside the scope of this report to refer to data sources in every country.

Through industry knowledge and experience, a number of broad presumptions have been made before providing estimates of by-products (Table 11). However, for almost every presumption there are exceptions.

4.1 Species processed at sea and extent of processing

Not all species are processed at sea, and the extent of processing varies significantly. Table 12 highlights the variability of processing activities carried out at sea for examples of commercially important fish and shellfish.

Table 11: Presumptions and exceptions regarding at sea processing

Presumption	Exceptions
Majority of demersal species are processed at sea. Minimum is gutting but can vary to fully processed i.e. filleted and frozen.	• Small demersal species can be landed whole. • Other components may be retained as products for human consumption, for example heads, cheeks.
When demersal fish are gutted at sea the viscera are typically thrown overboard.	• This does not apply to larger vessels, who are processing at sea, if they have on-board by-product processing and storage. • Livers may be retained by smaller vessels so long as the livers are a suitable size.
Majority of pelagic fish are landed whole, processed on-shore.	• Pelagic fleets vary and there are pelagic freezer fleets, who are processing and freezing at sea, however they represent a small proportion of global pelagic vessels. • By-products may be retained and used in feed / food uses.
Tuna is bled at sea, maybe gilled and gutted	• Tuna processing at sea is highly variable and includes a significant amount of tuna retained whole. This is frozen whole but the blood leaches into the brine solution during freezing. • The extent of processing varies depending on size / species of tuna, market requirements.
Crustacea (prawns, shrimp, crabs, nephrops) are landed whole / intact	• Cold water prawns can be processed at sea (peeled), or just frozen and landed whole, or landed chilled, whole, depending on whether fishing is inshore or deep-sea fishing • Crabs can be landed whole / live or claws only.. • Nephrops can be landed whole/live, whole/dead or as tails (head/ claws removed at sea)
Molluscs / bivalve molluscs are not processed at sea	• None identified

Table 12: Extent of processing at sea for a number of main types of fish and shellfish

	Evisceration (gutting)	De-heading	Skinning	Trimming (cutting fins and belly flaps)	Filleting (or portion creation)	Gill Removal Bleeding
Demersal						
Cod Hake Haddock	X	X	X	X	X	
Alaskan Pollock	X	X			X	
Atlantic cod	X	X				
Patagonian toothfish	X	X	X	X		
Pelagic fish						
Mackerel, herring, blue whiting	X				X	
Skipjack Tuna						X
Yellowfin Tuna						X
Shellfish		De-heading / de-clawing				
Squid	X					
Crabs		X				
Prawns		X			X	

Key findings

- Demersal species are typically gutted as a minimum, although there are exceptions.
- Pelagic fish are typically landed whole, although there are exceptions.
- Tunas can be processed to varying degrees or landed whole.
- Of the shellfish, squid are most likely to be processed. Crustacea may be processed in multiple formats, although the main trade is for whole/live animals.

4.2 By-product yields and conversion rates

To estimate the weight of by-products from global catches, it is necessary to use conversion rates (% yield) which estimate the proportion of by-product as a percentage of the live weight equivalent of fish.

Complete datasets on by-product yield rates are limited to a few fish species, therefore the yield rates used were obtained for generic groups (e.g. flatfish and roundfish) or derived from averaging the available information on individual species of fish within a fish category (see Table 13).

The main by-product categories relating to processing at sea comprise:

- 'Guts' (viscera)
- The combined weight of the 'head and guts'
- The by-products produced by processing a fish into skinless fillets.

Further detail on the variation in percentage yields obtained for different fish species/fish 'types' is presented in the Appendix.

Table 13: Percentage yields of by-product categories for main 'types' of fish, based on live weight.

Fish Type	By-product categories and % yields		
	Guts (%)	Head and Guts (%)	By products after filleting (%)
Roundfish (demersal)	16	37	64
Flatfish (flounders etc)	9	31	60
Tuna	8	26	50
Squid	n/a	n/a	30

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4. Processing at sea: by-product yields and current practice

4.3 Current practice with processing and retention of by-products at sea

This section includes an overview of the responses from the questionnaires and surveys (Tables 14 to 18). They provide a simple overview of the level of processing carried out on some of the main species captured across different geographical locations. The limited number of questionnaire responses (8) means this is only a broad indication for a limited number of species.

Table 14: Commercial species and current practice for on-board by-products (based on 8 questionnaire responses)

	Species	At-sea processing	% Wt. of catch processed at sea	% By-product retained on board	By products retained on board
North America	Alaskan Pollock	Gutting Heading Filleting	50%	>50%	Livers; Head; Skin Belly Flaps; Frames Backbones
Europe (freezing at sea fleet only)	Cod, Haddock	Filleting	100%	100%	Guts; Liver; Heads; Cheeks; Tails; Fins; Scales; Skin; Belly flaps / other trimmings; Frames (backbone)
South America, Peru	Mahi Mahi (*Coryphaena hypurus*) Humboldt or giant squid (*Dosiducus gigas*) sharks	Gutting heading	100%	0%	

Findings

- By-products can be retained or discarded overboard if the on-board storage is full.
- The by-products generated by the artisanal fleet for mahi mahi, Humboldt squid and sharks are often fed on by seabirds after being discarded.

Table 15: Commercial species and current practice for on-board by-products (tuna)

	Species	At-sea processing	% Wt. of catch processed at sea	% By-product retained on board	By-products retained on board
Europe - Netherlands	Skipjack tuna; Yellowfin tuna; Bigeye tuna	No	n/a	n/a	n/a

Findings

- Catch is frozen whole, round on-board.
- All tuna is fished by industrial, large-scale purse-seine vessels.
- Vessels brine-freeze the catch within 15 minutes of hauling the nets on board.

Table 16: Commercial species and current practice for on-board by-products (toothfish)

	Species	At-sea processing	% Wt. of catch processed at sea	% By-product retained on board	By-products retained on board
Australia	*Dissostichus eleginoides, Dissostichus mawsoni*	Gutting; heading; heading and gutting	100%	Cheeks, lugs (about 10% of total generated)	Cheeks, lugs, skin, belly flaps, frames

Findings

- Some by-products are retained on board and supplied for human consumption.
- There is limited ability to process by-products due to lack of space, lack of on-board treatment/storage, or a lack of time for the crew to process them.
- There is limited/no demand for by-products, so they are not cost-effective to retain.
- Catching season is limited to 10 days – so fishers focus 100% on retaining the most valuable product.

Table 17: Commercial species and current practice for on-board by-products (various)

	Species	At-sea processing	% Wt. of catch processed at sea	% By-product retained on board	By-products retained on board
Australia	Toothfish, Icefish, Orange Roughy, Red snapper, Gold band snapper, Blue-eye trevalla, Saddle tail snapper	gutting, heading, heading and gutting, production of skin-on fillets	Toothfish (100%), Icefish (100%), Orange roughy (100%), Red snapper (100%), Blue eye trevalla (100%)		Toothfish heads, cheeks

Findings

- Some by-products are retained for human consumption.
- Generally, guts are removed from finfish for food safety and storage reasons.
- With some wholefish (e.g. icefish), guts are retained as the fish are cooked whole.
- Lack of space on board constrains ability to retain all by-products.

Table 18: Commercial species and current practice for on-board by-products (various, tuna)

	Species	At-sea processing	% Wt. of catch processed at sea	% By-product retained on board	By-products retained on board
PNA Nations - Palau, FSM, RMI, Kiribati, Tuvalu, Nauru, Solomon Is, PNG and Tokelau	*Katsuwonus pelamis* *Thunnus albacares* *Thunnus obesus*	Freezing only	n/a	n/a	n/a

Findings

- The purse seine fishery brine-freezes the whole catch in typically 65-tonne capacity wells.
- The bloody brine is pumped out when pulling temperature down to -18°C and is discharged either at sea or in port.

Key findings

- Demersal species are typically gutted, and often de-headed.
- Tunas can be processed or landed whole.
- Targeted by-products (e.g. cheeks, trimmings) are for human consumption. Combined by-products are for fishmeal production.
- Lack of space and capacity limits the ability to process and retain by-products.
- There is no market demand/value for the majority of by-product formats.
- Operators prioritise the valuable fishery products.

KNOWLEDGE GAPS

- Information on processing activities at sea according to location (countries)
- Information on processed volumes/format produced on a regional basis
- Information on processed volumes/format retained on board for specified uses (human/non-human)
- Information on processed volumes/format discarded from vessels
- Information on processing volumes/format by main commercial species
- Information on processed volumes/format discarded from vessels

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5. Nutritional composition of by-products

The priority for deriving nutritional value has traditionally focused on the edible portions of seafood products, i.e. the typical formats such as fillets, meats etc.

For fish and shellfish products, in Europe for example, there are national reference databases providing standard nutritional data for a wide variety of foods, prepared in a wide variety of formats. One such example is McCance and Widdowson's (Composition of foods integrated dataset (CoFID), 2015, updated 2021) in the UK. This data does not include by-products and there is seemingly no equivalent for by-products.

While there is data available on the composition of by-products it is primarily focused on specific commercially important species, notably in the northern hemisphere, or on emerging species of significant value. Species produced in aquaculture have been a recent area of focused research.

There is much data available for the converted products after further processing, e.g. dried powders/flours, ensiled material, fermented sauces, feed ingredients, meals, oils etc.

From the data available it is evident that by-products have been studied in varying degrees. This ranges from detailed analysis of single by-products (e.g. eyes, bones, skin) through to combinations of by-products (e.g. head, viscera) to identify valuable components (Table 19).

For human dietary purposes, the main area of interest is fundamental nutritional characteristics (e.g. protein, minerals, and oils/lipids). By compiling various publicly available sources, it is possible to provide broad nutritional information for by-products.

The data available shows fish by-products provide vital vitamins, minerals and proteins which are essential in the diet.

This section of the report provides summary data for each area of nutrition. See Appendix for detailed data.

5.1 Proximate composition (moisture, protein, fat)

The composition of seafood varies according to the type of species, sex, age, nutritional status, time of year (e.g. spawning) and overall health. This can result in significant variations in levels of moisture, protein and fat.

This variation is also seen in the proximate composition data for by-products (Tables 20 and 21).

Table 19: Summary of valuable components of marine by-products (Shahidi, 2006) (Francisco J Marti-Quijal, 2019)

Lipids	Proteins	Other components
• Oils • Omega-3: EPA, DHA, fatty acids • Phospholipids • Squalene • Vitamins • Cholesterols	• Enzymes • Hydrolysates (proteins chemically or enzymatically broken down to peptides) • Surimi • Thermostable dispersions • Peptides, amino acids • Gelatine, collagen • Protamine • Hyaluronic acid	• Nucleic acid • Calcium • Phosphorous • Bioactive compounds • Colours • Chitin / chitosan / glucosamine / chondroitin

Table 20: Proximate composition value ranges for different species (various sources, see Appendix)

	Moisture	Protein	Fat	Ash
	% wet weight			
Cod	71-85	13-24		
Pollock	81.3-82	11-19	1.9-3	3.6-3.7
Halibut (heads only)	65.5	11.6	16.2	4.1
Salmon (Alaskan)	67-81	13-16	2-16	1-4
Haddock		7-18		
Ling		8-20		
Crab (various species)	71-77	8-14	1-2	9-11

Table 21: Proximate composition of 'fish by-products' (Ghaly, 2013)

	Crude protein	Fat	Ash	Crude fibre
	% dry matter			
Non-specified 'fish by-products'	57.92 ± 5.26	19.10 ± 6.06	21.79 ± 3.52	1.19 ± 1.21

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If by-products were to be separated by the component parts, it is evident that each part would yield a different composition, as can be seen in data for Alaska pollock (Table 22).

Key findings

- From the data it is evident that fish products can be a valuable source of proteins and fats. They contain high-quality proteins and lipids with long-chain omega-3 fatty acids.
- Detailed information on the fatty acids content of by-products is more limited but it is evident that by-products are a source of saturated fatty acids (SFA), polyunsaturated fatty acids (PUFAs), and monounsaturated fatty acids (MUFAs). Omega-3 and omega-6 fatty acids are PUFAs, and omega-9 fatty acids are usually MUFAs.
- The composition of by-products varies between species and component parts. Understanding the composition of different by-products is useful in order to utilise by-products in specific products or uses.
- The nutritional value of by-products will fluctuate. However, it will be particularly influenced by the quality of the raw material. By-products are typically prone to more rapid spoilage and would need to be preserved to avoid loss of nutritional value.

Table 22: Proximate composition of different components of Alaska pollock (Alaska Sea Grant College Program, 2003)

	Moisture	Protein	Fat	Ash
	Pollock by-product composition (calculated: adjusted 8% moisture) (values in %)			
Whole fish	8	65.7	15.5	10.8
Fillets	8	84.9	1.9	5.2
Head	8	67.4	5.2	19.4
Frame	8	73.6	3.9	14.5
Viscera	8	41.2	47.2	3.6
Skin	8	87.5	1.7	2.8

5. Nutritional composition of by-products

5.2 Micronutrients and amino acids

Fish by-products provide levels of micronutrients that are essential in the diet. These have been quantified in varying levels, depending on the species and by-product components (see Appendix). Micronutrients identified in by-products include:

- Vitamins A, D, B, particularly B-12
- Minerals: calcium, copper, iodine, iron, magnesium, manganese, potassium, phosphorous, selenium, sodium, zinc.

Amino acids have also been found in by-products. The human body needs different amino acids to maintain health and normal functioning. The data shows amino acids are found in varying levels, depending on the species and by-product components.

The amino acids identified in by-products include alanine, arginine, aspartic acid, cysteine, glutamic acid, glycine, hydroyproline, isoleucine, leucine, lysine, methionine, phenylamine, proline, serine, valine, histadine, theonine, and tyrosine.

5.3 Contaminants

Numerous studies have been undertaken on the benefits versus risks of eating seafood, including by the WHO and FAO (World Health Organization & Food and Agriculture Organization of the United Nations, 2011). Seafood is an important part of the global diet but there can be issues in some products, derived from specific species caught in specific areas. This may be particularly true for some by-products, notably viscera and livers, where contaminants are more likely to accumulate. Other by-products, such as heads and cheeks, are less likely to accumulate contaminants.

The benefits of seafood consumption far outweigh any risks (albeit vulnerable groups need to follow specific advice tailored to their circumstances). This is based on known data relating to the typical edible portions like fillets, meats, loins etc. It is not evident if this conclusion applies to the range of by-products that may be consumed.

By-products for direct human consumption (e.g. cheeks) are subject to exactly the same safety requirements that apply to any seafood products for the human food chain. When by-products are further processed and used in the production of new products (e.g. oils, protein powders, meals, sauces etc) they undergo additional testing and processing. Oils, for example, are refined to ensure their safety.

From the limited data identified, by-products may be a source of contaminants. In 2011, the WHO and FAO recommended that countries/regions:

- "Develop, maintain and improve existing databases on specific nutrients and contaminants...in fish consumed in their region."
- "Develop and evaluate risk management and communication strategies that both minimize risks and maximize benefits from eating fish".

KNOWLEDGE GAPS

- The data available on by-products is variable in content, scope and analytical method. This makes it challenging to draw comparisons and conclusions.
- Data is not available for all the commercially caught species where by-products are produced.
- Data is not available to better understand if specific by-products are better targeted or used for specific uses.
- The loss of nutritional value influenced by spoilage of by-products.
- The levels of any contaminants in by-products, particularly internal organs.
- The benefits and risks of eating different by-products.


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6. Estimates of by-products at sea and their protein value

Information on by-product yields (Section 4) is used to produce estimates of by-product quantities for each ISSCAAP grouping/species.

Detailed information on the exact amount or proportion of catch that is processed at sea is unavailable. It is evident from the questionnaires and anecdotal information that the proportion of the catch that is processed at sea is highly variable. Similarly, the extent of processing can vary, for example, from partial processing (gutting) through to fully filleting.

To provide an estimate of by-products produced at sea, two different ranges are used to reflect the variations in the quantity of catch that may be processed and the extent of processing that may be undertaken:

1. Three proportions (25%, 50% and 100%) are applied to the total catch quantity. These provide a basis for quantifying the amount of the catch that may be processed at sea.
2. Three levels of processing at sea are also included (gutted, headed and gutted, fully processed). These reflect the main variations in the extent of by-products produced, based on the weight of the whole fish (i.e. live weight). For example, for cods, hakes and haddocks:
   - Gutting generates 16% by-products.
   - Heading and gutting generates 37% by-products.
   - Fully filleting generates 64% by-products.

The combination of these ranges has been applied to the total weight of the global catch, for each main species groups.

6.1 Estimates of by-products produced at sea, by species groups

When the two ranges are applied to the total catch of each main group or species (based on ISSCAAP grouping/species), it is possible to provide broad estimates (Tables 23 to 30).

The catch data is presented as tonnes of live weight. By-product data is calculated by product weight.

Table 23: Estimated tonnes of by-products: Cods hakes and haddocks

Cods hakes and haddocks (Total catch: 9.3 million tonnes)	Quantity of by-products produced by percentage of catch processed (millions of tonnes)			By-product quantity range (millions of tonnes)
	25%	50%	100%	
By-product tonnes: Guts (16%)	0.37	0.74	1.49	0.37 to 1.49
By-product tonnes: Head & Guts (37%)	0.86	1.72	3.44	0.86 to 3.44
By-product tonnes: Full processing into skinless fillets (64%)	1.49	2.98	5.95	1.49 to 5.95

Table 24: Estimated tonnes of by-products: flounder, halibut and soles

Flounder halibut and Soles (Total catch: 1 million tonnes)	Quantity of by-products produced by percentage of catch processed (millions of tonnes)			By-product quantity range (millions of tonnes)
	25%	50%	100%	
By-product tonnes: Guts (9%)	0.02	0.05	0.09	0.02 to 0.09
By-product tonnes: Head & Guts (31%)	0.08	0.15	0.31	0.08 to 0.31
By-product tonnes: Full processing into skinless fillets (60%)	0.15	0.30	0.60	0.15 to 0.60

Table 25: Estimated tonnes of by-products: tunas, bonitos, billfish*

Tuna Bonitos and billfish (Total catch: 8.1 million tonnes)	Quantity of by-products produced by percentage of catch processed (millions of tonnes)			By-product quantity range (millions of tonnes)
	25%	50%	100%	
By-product tonnes: Guts (8%)	0.16	0.32	0.65	0.16 to 0.65
By-product tonnes: Head & Guts (26%)	0.53	1.05	2.11	0.53 to 2.11
By-product tonnes: Full processing into skinless fillets (50%)	1.01	2.03	4.05	1.01 to 4.05

The research for this report found conflicting information on the extent of tuna processing at sea. Tunas will also be landed whole, as indicated from the responses to the questionnaires. The figures for tuna by-products at sea are included for all tunas, as it is impossible to separate the data sources.

Table 26: Estimated tonnes of by-products: Miscellaneous demersal fish

Miscellaneous demersal fish (Total catch: 2.8 million tonnes)	Quantity of by-products produced by percentage of catch processed (millions of tonnes)			By-product quantity range (millions of tonnes)
	25%	50%	100%	
By-product tonnes: Guts (16%)	0.11	0.22	0.45	0.11 to 0.45
By-product tonnes: Head & Guts (37%)	0.26	0.52	1.04	0.26 to 1.04
By-product tonnes: Full processing into skinless fillets (64%)	0.45	0.90	1.79	0.45 to 1.79

Table 27: Estimated tonnes of by-products: 'Marine fish - not identified'.

Marine fish - not identified (Total catch: 10.5 million tonnes)	Quantity of by-products produced by percentage of catch processed (millions of tonnes)			By-product quantity range (millions of tonnes)
	25%	50%	100%	
By-product tonnes: Guts (16%)	0.42	0.84	1.68	0.42 to 1.68
By-product tonnes: Head & Guts (37%)	0.97	1.94	3.89	0.97 to 3.89
By-product tonnes: Full processing into skinless fillets (64%)	1.68	3.36	6.72	1.68 to 6.72

Table 28: Estimated tonnes of by-products: 'Marine coastal fisheries'.

Marine coastal fisheries (Total catch: 7.5 million tonnes)	Quantity of by-products produced by percentage of catch processed (millions of tonnes)			By-product quantity range (millions of tonnes)
	25%	50%	100%	
By-product tonnes: Guts (16%)	0.30	0.60	1.20	0.3 to 1.20
By-product tonnes: Head & Guts (37%)	0.69	1.39	2.78	0.69 to 2.78
By-product tonnes: Full processing into skinless fillets (64%)	1.20	2.40	4.80	1.20 to 4.80

Table 29: Estimated tonnes of by-products: 'Squids'

Squids (Total catch: 2.8 million tonnes)	Quantity of by-products produced by percentage of catch processed (millions of tonnes)			By-product quantity range (millions of tonnes)
	25%	50%	100%	
By-product tonnes: Full processing into tubes (30%)	0.21	0.42	0.84	0.21 to 0.84

Table 30: Estimated tonnes of by-products: 'Sharks, rays and Chimera'

Sharks rays and Chimera (Total catch: 0.8 million tonnes)	Quantity of by-products produced by percentage of catch processed (millions of tonnes)			By-product quantity range (millions of tonnes)
	25%	50%	100%	
By-product tonnes: Guts (9%)	0.02	0.04	0.07	0.02 to 0.07
By-product tonnes: Head & Guts (31%)	0.06	0.12	0.24	0.06 to 0.24
By-product tonnes: Full processing into skinless fillets (60%)	0.12	0.24	0.48	0.12 to 0.48

KNOWLEDGE GAPS

- Complete by-product information on each species (commercial)
- Complete by-product information on ISSCAAP grouping/categories
- Information on the proportion (%) of each species/ ISSCAAP grouping processed at sea

6. Estimates of by-products at sea and their protein value

6.2 Estimated total quantity of by-products from processing at sea

Combining the data from all the species groups provides an estimated range of by-products from processing at sea (Table 31). Because of the assumptions and generalities, these figures should be treated with extreme caution and considered only as a broad indication.

6.3 Potential nutritional value of at-sea by-products

Focusing purely on fish as a protein source, the earlier data showed a range of protein levels from 10% to 20% across different by-product types and species. Applying this range to the estimated quantity of by-products potentially available at sea, it is possible to provide an indication of the quantity of protein available if those by-products could be available for consumption (Table 32).

The data in Table 32 is a calculated estimate, based on limited information and incomplete data. It serves only as an indicator of the potential value of at-sea by-products.

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Table 31: Estimated quantities of by-products from processing at sea (all species groups)

All species groups	Quantity of by-products produced by percentage of catch processed (millions of tonnes)			By-product quantity range (millions of tonnes)
	25%	50%	100%	
If gutted at sea*	1.41	2.81	5.63	1.41 to 5.63
If headed and gutted at sea*	3.45	6.90	13.79	3.45 to 13.79
If fully processed into skinless fillets / squid fully processed into squid into tubes (30%)	6.31	12.62	25.23	6.31 to 25.23
*excludes squid				

Table 32: Estimated total of protein available if at sea by-products derived from the species groups identified in this report, were available for human consumption

All species groups	By-product estimated quantity range (millions of tonnes)	Potential protein available (based on wet weight, all by-product types)	Estimated quantity of protein available (millions of tonnes)	
			Min.	Max.
If gutted at sea*	1.41 to 5.63	10% to 20%	0.14	1.13
If headed and gutted at sea*	3.45 to 13.79		0.35	2.76
If fully processed into skinless fillets / squid fully processed into squid into tubes (30%)	6.31 to 25.23		0.63	5.05

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7. Case studies

7.1 Frozen at Sea Fillets Association

Formed in 2000, the Frozen at Sea Fillets Association (FASFA) is the representative trade association of the frozen-at-sea (FAS) industry in the UK.

The FASFA vision is for a thriving, sustainable and profitable fish and chip industry in the UK, through the provision of high-quality FAS cod and haddock fillets sourced from responsibly managed stocks.

FASFA members include international fishing companies, fishing vessels and distributors of FAS filleted cod and haddock. More information about FASFA is on its website – fasfa.co.uk

Fishing and products

Fishing areas and regions, and target catch
FASFA membership covers companies based in Norway, Iceland, the Faroe Islands, Russia, Greenland and the UK.

The major fishing regions include:
- ARCTIC SEA (Major Fishing Area 18)
- ATLANTIC, NORTHEAST (Major Fishing Area 27)

Specific fishing zones include:
- Areas I, IIa, IIb
- Val, Vall
- XIVa, XIb

The catch is landed into various ports across the different regions.

The target species for the vessels represented by FASFA are demersal fish (whitefish, groundfish), specifically cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). Depending on quota and market requirements, vessels can switch to fishing for other species including saithe (*Pollachius virens*) and redfish (*Sebastes* spp.).

Products
FASFA members produce a significant volume of products in different formats. These formats are driven by market requirements and include frozen fillets.

The annual volume of frozen fillets produced by FASFA members has been static, in the region of 50,000 tonnes per annum; however, this has fluctuated in recent years.

At-sea processing

The FAS vessels are typically >60 m LOA and are designed to utilise every space for the production of their main products for human consumption, i.e. fish fillets.

They are highly mechanised operations, designed for the purposes of processing at sea. The vessels are at sea for long trips, at least 30 days, and can last up to 60 days. Fishing is undertaken in short tows/hauls to manage the throughput for the factory operation below deck. This optimises the quality as the fish are processed and frozen within four hours of capture.

After hauling, the catch is processed into the component parts:

- Products for human consumption are blast-frozen before cold storage.
- By-products removed during mechanised processing are collected and dispatched to a separate area of the processing deck where they are handled/stored.

By-product retention, storage and use

By-products are collected together as it is impossible to separate any of the component parts. This is due to the nature of processing (mechanised) and volume of throughput.

Using a conversion factor of 2.96 (average of the respective conversion factors for calculating live weight equivalent from frozen cod and frozen haddock fillets (EUMOFA)), this would equate to 98,000 tonnes of by-products generated from the frozen fillets portion of the catch.

The vessels may also produce headed and gutted (H&G) products. However no information was available on the quantities of these. The estimate of by-products (previous paragraph) does not include the by-products from processing whole fish into H&G fish.

Space within the vessels is prioritised for the production of fillets and other products for human consumption. The design of the vessel is such that every space is utilised for processing, handling and storage of the catch.

The by-product handling equipment has a specific throughput and will operate at maximum capacity. Such equipment will struggle to cope at times; for example, during peak production.

By-products, while being an income stream, are secondary to the human consumption products. Space limitations mean that some vessels can retain all the by-products produced, whereas other vessels may only retain a proportion of the by-products on board. For vessels that have limited storage space, or whose on-board fishmeal equipment cannot handle the volume of by-products, there is a need to dispose of the by-products at sea.

After landing, the processed by-products are supplied for the production of fishmeal and oil. The vessel lands the catch in various ports and will sell the processed/stabilised by-products to a local fishmeal processor. One example of fishmeal produced at sea by a FASFA member is Norwegian White Fishmeal (ramoen.no)

A number of Icelandic FASFA members have interests in an on-shore collagen production facility, producing collagen and gelatine from fish skins – codlagen.com

Challenges

The market will always drive the requirements for the landed products. The priority will remain products for human consumption; it would be challenging to retain a greater proportion of by-products due to the limitations in on-board space.

Processing at sea is challenging and subject to many external factors and future influences, including:
- Market demand for product formats may shift between semi and fully processed. This will affect the volume of by-products generated.
- Policy decisions can affect future decisions to invest in processing at sea, for example higher import trade tariffs for higher processed products.
- Fishery management issues such as quotas (availability, costs).
- Climate change (changing migratory patterns for key species).

UK Fisheries

Future outlook

- Continued focus on vessel efficiency in terms of operations.
- Fuel efficiency is a major future focus.

All information for this case study courtesy of FASFA. Acknowledgements: Julie Waites, Executive Director, Frozen at Sea Fillet Association (FASFA) – fasfa.co.uk

SPOTLIGHT ON THE KIRKELLA State-of-the-art freezer vessel registered in the UK

The Hull-based Kirkella was registered in June 2018 and is 81 m long. With 30 crew on board and automated processing, the first fish reach the on-board freezers 40 minutes after being caught.

The vessel's main fishing areas are Barents Sea, Greenland waters, NAFO (northwest Atlantic), and Norwegian Sea.

Each trawl lasts between 30 minutes and six hours, catching around 12 tonnes of fish per haul. The nets are hauled on board from the stern, then the catch is electronically stunned and conveyed to the onboard factory. The fish are filleted, frozen and packaged in a continuous, highly mechanised process.

The guts, skins and heads are stored separately and processed into fishmeal and used in animal feeds and as a fertiliser. Kirkella can store up to 780 tonnes of fish fillets at -28°C in her onboard cold store. By-product storage is 170 tonnes.

Ref: ukfisheries.net/kirkella-trawler

7. Case studies

7.2 At-sea Processors Association

The At-sea Processors Association (APA) is a trade association representing five member companies that participate principally in the Alaska pollock fishery and west coast Pacific whiting fishery. By weight, these groundfish fisheries account for more than one-third of all fish harvested in the US each year.

Further information is available online: www.atsea.org

About the fishery

The mid-water trawl Alaska pollock fishery is the largest fishery in the US and one of the largest fisheries in the world. Approximately 1.18 million tonnes are harvested annually.

The major fishing region is the US Eastern Bering Sea. The main target species are Alaska pollock (*Gadus chalcogrammus*) and west coast Pacific whiting (*Merluccius productus*).

Policy changes and drivers

In 1998, the American Fisheries Act introduced a fundamental change in fisheries management and quotas. Prior to this, the incentive was for vessels to catch as much fish as possible. However, the introduction of new policies and restrictions on fishing resulted in a significant shift towards total catch utilisation. This led to investment in new vessels and upgrades to existing vessels, ensuring the facilities on board could make use of all parts of the fish they caught.

Products
Pollock is typified as a high-volume, low-value fish, with maximum utilisation of the catch.

A variety of seafood products are produced on board including minced fish, fillets (pin bone out and/or deep-skin), surimi, and fish roe. Fish meal and fish oil are produced from non-flesh parts of the fish.

APA catcher/processor vessels retain and utilise 99.5% of their catch.

At-sea processing
The five members of the APA own and operate 13 US-flag catcher/processor vessels.

The vessels harvest, process, package and freeze the catch within hours of harvest.

Currently, 10 of the vessels have on-board fishmeal and 12 have fish oil producing capabilities. Of the three vessels without fishmeal capacity, one is scheduled for replacement and will include on-board fishmeal and fish oil capability. The remaining two vessels have on-board fish oil production capacity. The vessels range in size from 78 to 115 m LOA. They are highly mechanised operations, designed for the purposes of processing at sea and utilising the totality of the catch. Fishing trips generally last from 8 to 14 days.

The vessels offload their catch and refuel and restock supplies in Dutch Harbor, Alaska. The various products are destined for a number of domestic and global markets. The fishmeal produced on board is typically exported to China. Fish oil can also be exported, but often in the summer B-season more fish oil is produced than can be stored on board the vessel, therefore it is burned as fuel. It is also used in nutraceutical products.

By-product retention, storage and use

Since the 1998 policy changes, the focus on catch utilisation has created a significant increase in product usage. This is clearly shown in the data and evidence available.

Data from 2016-2018 shows the variety of products produced by volume. Having this data broken down into component parts shows the utilisation of products that, in many other fisheries, would not be retained or landed.

It is evident that the traditional edible portion (fillet) is only a proportion of the number of products produced, with other important products (by weight) being surimi, fish meal and oil, and minced fish.

2016-2018 production by sector and Wild Alaska pollock product type (Bering Sea / Aleutian Islands)

Wild Alaska Pollock Product	Total production (MT)
Fillet	485,867
Surimi	584,076
Roe	53,316
Fish oil	80,155
Fishmeal	192,613
Head & gutted	73,775
Minced	80,996
Milt	2,901
Stomach	5,688
Bones	29,832
Whole fish	1,241
Belly flap	11
Other retained products	31

Over time, the product recovery rate (i.e. utilisation of the fish) has increased significantly (see graphs below).

Between 1999 and 2019, product recovery rates of pollock nearly doubled from 18.14 tonnes of finished product per 90.71 tonnes of round weight pollock catch in 1999 to nearly 36.28 tonnes of finished product per 90.71 tonnes of round weight pollock catch in 2019.

Product mixes have remained relatively stable over the time series, although there has been a slight increase in fish meal and fish oil production as well as some other ancillary products.

Valuing the catch

A recent life cycle analysis for Alaska pollock shows the yields and wholesale prices for various products.

It is evident that the maximum yield is being recovered from the total catch.

There are significant differences in the wholesale values of the component parts of the catch by weight. The highest value was seen for roe, with fillets, surimi and minced fish yielding similar values. Where markets are available for products there is clearly an economic value in all the parts of the catch.

Yield rates and economic values (wholesale price) for Wild Alaska Pollock products (Bering Sea / Aleutian Islands (BSAI))

Wild Alaska Pollock Product	Yield rates (percent recovered from fresh pollock biomass in final product mass)	Economic value (wholesale price)
	Average of all sectors	$ per MT
Fillet	100%	$2,580.39
Surimi	109.9%	$2,412.27
Roe	100%	$6,756.11
Fish oil	3.57%	$1,316.67
Fishmeal	8.59%	$1,893.33
Head & gutted	100%	$2,055.95
Minced	100%	$2,553.05
Milt	100%	$1,316.67
Stomach	100%	$2,403.33
Bones	100%	$1,316.67
Whole fish	100%	$1,316.67
Belly flap	100%	$1,316.67
Other retained products	100%	$1,316.67

Future outlook

Continued focus on total catch utilisation
Investing in vessels with equipment on board to undertake at-sea processing and retain 100% of the catch.

Acknowledgements

All information for this case study courtesy of and reproduced with permission of the At-sea Processors Association. www.atsea.org

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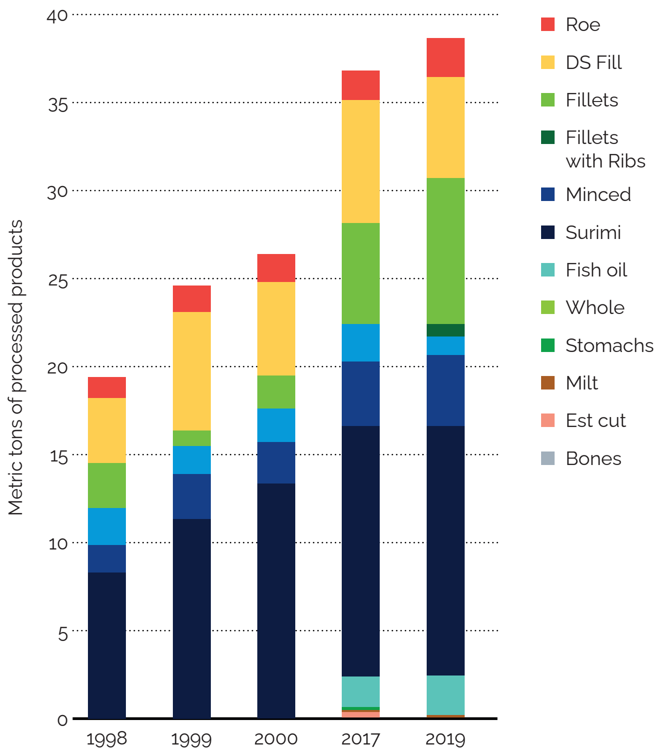
Fig. 2 Average product mix and yield 1998-2000, 2017 & 2019
(Per 100 metric tonnes of round pollock over the course of the fishing year)



7. Case studies

7.3 Iceland – 100% Fish Project

(All information and images reproduced courtesy of the website www.sjavarklasinn.is/en/100-fish)

Iceland has had a leading reputation for the utilisation of by-products for a number of years, driven by the importance of seafood to the economy.

Ten years ago, the Iceland Ocean Cluster established the 100% Fish Project. The aim of this was to maximise the utilisation of the catch, increase the value of the catch, support new business, increase employment, and avoid wasting a valuable resource.

The value of collaboration

The Iceland Ocean Cluster has brought together seafood businesses in a network with the research community and new businesses. This has led to the sharing of challenges and solutions.

Research

Working with researchers and technology providers has led to improvements in innovation which have helped maximise the by-products that can be used. The seafood industry has also had to innovate, to improve its handling and processing of by-products.

Value creation

Over the past three decades Iceland has invested heavily in this area, and this has led to significant changes in maximising the value of the catch and the utilisation of by-products. The 100% Fish Project states that:

- Icelandic cod producers typically use up to 80% of their raw material.
- Fillet yield has increased by as much as 20% over the past two decades.
- Since the 1990s, the utilisation of fishery by-products has increased 30-fold.
- The export value per cod kilogram has risen by a factor of 4.
- Icelandic producers are getting at least 30% more value from each cod than most developed countries.

Much of this has been driven by innovation and investment, involving multiple businesses and organisations working together. There are multiple companies in Iceland that are now involved in the utilisation of fishery by-products.

New products

Beyond the production of seafood, Iceland now produces and trades in:

- Liver
- Cosmetics
- Smoked & dried fish
- Medical products
- Fish leather
- Roe & milt
- Supplements & nutraceuticals
- Omega-3 oil

Knowledge transfer

The Icelandic Ocean Cluster is working with other groups, including in the USA and Canada, to transfer knowledge and skills. Its aim is to help support other clusters to maximise the value of the catch in their fisheries.

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8. Considerations for on-board retention of by-products

The retention of by-products on board fishing vessels should be considered in a wider context. For example, there may be unintended consequences for the environment, the crew or the vessel; or there may be other factors that have to be considered before by-products could or should be retained, for example market requirements.

The table below provides a summary of some of the considerations that were identified during the production of this report.

Table 33: Summary of considerations if a higher volume of by-products were to be retained on-board

	Considerations
Ecosystem	Impact on seabirds, predatory species, bottom feeders, general nutrient cycle
On-vessel	Fish by-products, especially when containing viscera, deteriorate very rapidly. Requires on-board available preservation techniques suited to the types of by-product and market requirements
	Vessel design is optimised for current on-board handling and processing, there may be requirements for vessel modifications
	Increased work for crew to sort and separate the catch into component parts
	Vessel sizes are limited in terms of storage and handling capabilities
	Suitability for small scale fishers (artisanal) would be different compared to larger vessels
	Fishing conditions; warm-water species vs cold-water species, ambient temperatures (effect on spoilage)
Food safety	On-board facilities not geared at handling/storing by-products
	Prevention of cross-contamination if viscera (offal) are retained on-board
	Need for rapid handling and effective preservation; some by-products will spoil much more rapidly than products for human consumption
	Heavy metals and contaminants; extent of evidence available on the benefits vs risks of eating portions that may have levels higher than regulatory safety limits
Economic / market	Creating a market for by-catch or selective parts of fish (if value becomes significant for example brown crab in UK and Ireland, landing claws, market for carapace is volatile and economically challenging at times)
	Offsetting the landed value of by-products against the value of catch; with limited space on-board fishing vessels, there could be reduced income for fishers
	Displacement of ingredients currently used for feed purposes, given the forecast demand in marine ingredients for future growth in aquaculture


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9. Conclusions and recommendations

Publicly available data is limited in order to quantify the extent of at-sea by-products. However, by using different datasets covering global fish catch, types of by-products and processing yields, catch areas (regions/flag states), and types of fishing vessels, it has been possible to make some very broad statements and estimates. However, these are only indicative. There are major knowledge gaps to consider before estimates can be refined.

From the limited responses received it is evident that the extent of retaining by-products on board is highly variable. Larger vessels (>35 m LOA) which are processing and freezing at sea are most likely to be retaining by-products and using these for human consumption/products, or for feed ingredients. It is apparent that even the larger vessels have limitations when it comes to by-product retention, from on-board storage, crew time to process, product quality and safety, through to perhaps the biggest limitation which is the low market value in most parts of the world. Apportioning by-products the time, valuable storage space and preservation required will always be secondary to the more significant value of the primary edible products.

On-board retention of by-products should not be seen in isolation, as it is evidently not simply a case of encouraging fishers to retain them. Many factors should be considered, not least the usual challenges of balancing supply and demand, but also potential income displacement, vessel design, environmental impacts of removing nutrients from the sea, food safety, on-shore infrastructure for handling, storage and product conversion where necessary.

There are successful examples for maximising the value of the catch, notably in the northern hemisphere. These are a result of long-term investment and collaboration between different parts of the seafood industry, technology providers, business innovators, science and research, and funders. It is a model that is currently aspirational for many other regions, but sharing that knowledge and understanding is instrumental to ensuring the success of any future initiatives to retain and add value to by-products.

Recommendations:

- Filling knowledge gaps on species, fishing vessels, current practices.
- Collaboration with leading nations (e.g. Iceland, Norway) to share knowledge and insight.
- Understanding the role of innovation and how this may be best used from the on-board processes and storage through to on-shore infrastructure and product development.
- Market identification and development; seafood is globally traded and that includes by-products. Understanding the demand for by-products in different countries is invaluable.
- Better knowledge of the quality, safety and hygiene requirements for by-products from at-sea processing through to legal requirements e.g. for processing, handling, trade with different nations.
- Understanding the nutritional composition of different by-products for a broader range of species would be useful, to understand the benefits versus risks of directly consuming these products.


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Appendices

Appendix I: Classification of fishing gears

International Standard Classification of Fishing Gears (ISSCFG), Rev.1 (2016) (He, 2021)			
Gear categories (First tier)	**Subcategory (Second tier)**	**Standard abbreviations**	**ISSCFG code**
SURROUNDING NETS			01
	Purse seines	PS	01.1
	Surrounding nets without purse lines	LA	01.2
	Surrounding nets (nei)	SUX	01.9
SEINE NETS			02
	Beach seines	SB	02.1
	Boat seines	SV	02.2
	Seine nets (nei)	SX	02.9
TRAWLS			03
	Beam trawls	TBB	03.11
	Single boat bottom otter trawls	OTB	03.12
	Twin bottom otter trawls	OTT	03.13
	Multiple bottom otter trawls	OTP	03.14
	Bottom pair trawls	PTB	03.15
	Bottom trawls (nei)	TB	03.19
	Single boat midwater otter trawls	OTM	03.21
	Midwater pair trawls	PTM	03.22
	Midwater trawls (nei)	TM	03.29
	Semi pelagic trawls	TSP	03.3
	Trawls (nei)	TX	03.9
DREDGES			04
	Towed dredges	DRB	04.1
	Hand dredges	DRH	04.2
	Mechanized dredges	DRM	04.3
	Dredges (nei)	DRX	04.9
LIFT NETS			05
	Portable lift nets	LNP	05.1
	Boat-operated lift nets	LNB	05.2
	Shore-operated stationary lift nets	LNS	05.3
	Lift nets (nei)	LN	05.9
FALLING GEAR			06
	Cast nets	FCN	06.1
	Cover pots/Lantern nets	FCO	06.2
	Falling gear (nei)	FG	06.9

International Standard Classification of Fishing Gears (ISSCFG), Rev.1 (2016) (He, 2021)			
Gear categories (First tier)	**Subcategory (Second tier)**	**Standard abbreviations**	**ISSCFG code**
GILLNETS AND ENTANGLING NETS			07
	Set gillnets (anchored)	GNS	07.1
	Drift gillnets	GND	07.2
	Encircling gillnets	GNC	07.3
	Fixed gillnets (on stakes)	GNF	07.4
	Trammel nets	GTR	07.5
	Combined gillnets-trammel nets	GTN	07.6
	Gillnets and entangling nets (nei)	GEN	07.9
TRAPS			08
	Stationary uncovered pound nets	FPN	08.1
	Pots	FPO	08.2
	Fyke nets	FYK	08.3
	Stow nets	FSN	08.4
	Barriers, fences, weirs, etc.	FWR	08.5
	Aerial traps	FAR	08.6
	Traps (nei)	FIX	08.9
HOOKS AND LINES			09
	Handlines and hand-operated pole-and-lines	LHP	09.1
	Mechanized lines and pole-and-lines	LHM	09.2
	Set longlines	LLS	09.31
	Drifting longlines	LLD	09.32
	Longlines (nei)	LL	09.39
	Vertical lines	LVT	09.4
	Trolling lines	LTL	09.5
	Hooks and lines (nei)	LX	09.9
MISCELLANEOUS GEAR			10
	Harpoons	HAR	10.1
	Hand implements (Wrenching gear, Clamps, Tongs, Rakes, Spears)	MHI	10.2
	Pumps	MPM	10.3
	Electric fishing	MEL	10.4
	Pushnets	MPN	10.5
	Scoopnets	MSP	10.6
	Drive-in nets	MDR	10.7
	Diving	MDV	10.8
	Gear nei	MIS	10.9
GEAR NOT KNOWN			99
	Gear not known	NK	99.9

Nei = not elsewhere identified

Appendices

Appendix II: Questionnaires and responses

Questionnaire 1 – Detailed

Section 1. About this questionnaire
This questionnaire is aimed at collecting information on processing seafood at sea and the generation of by-products at sea. We are looking for an overview of current practices in fisheries across the world. For the purposes of this survey, by-products refer only to the parts of fish and shellfish removed during processing at sea that are not typically classed as the edible portion (i.e. fillet, loin, tail, meat etc). Please **DO NOT** include any information on by-catch i.e. any part of the catch that is non-target and / or not retained. If you run out of space, please continue on the second worksheet (called supplementary)

Section 2. Background information			
Name	*Insert country of person completing this form*		
Country	*Insert name of person completing this form*		
Fishery region (e.g. FAO region)	*specify all that apply*	*specify all that apply*	*specify all that apply*
	specify all that apply	*specify all that apply*	*specify all that apply*
Main types of fish caught ***Please delete any that do not apply***	Demersal	Pelagic	Crustacea (crabs, lobster, prawns etc)
Species in the fishery. ***Please list the top 10 main species caught for commercial purposes***	*Species name*	*Species name*	*Species name*
	Species name	*Species name*	*Species name*
	Species name	*Species name*	*Species name*
	Species name		

Section 3. Catch information			
Approximately what percentage of the catch is processed at sea?			
None (all landed intact)			
Species name	%	*Species name*	%
Species name	%	*Species name*	%
Species name	%	*Species name*	%
Species name	%	*Species name*	%
Species name	%	*Species name*	%

Please provide more information about the by-products produced from the species caught			
	Which by-products are generated	**Are they retained on board (select yes / no from dropdown)**	**Approximately what % (by weight) is retained on board**
Species name	list all that apply		%
Species name	list all that apply		%
Species name	list all that apply		%
Species name	list all that apply		%
Species name	list all that apply		%
Species name	list all that apply		%
Species name	list all that apply		%
Species name	list all that apply		%
Species name	list all that apply		%
Species name	list all that apply		%

List of by-products for reference	
All	Scales
Guts	Lugs (pectoral fin and bone)
Livers	Belly flaps
Heads	Frames (backbone)
Cheeks	Skin
Tails	Others (e.g. blood, roe, milt)
Fins	
Shellfish e.g. body parts, heads, shell (crustacea only)	

Section 4. Processing at sea	
What processing is undertaken on the catch? (please state yes or no, using the dropdown selection)	
Gutting	
Heading	
Heading and gutting	
Production of fillets (and other edible portions)	
Skin on	
Skin off	
Other	*please specify*

What by-products are generated? (select yes / no from the dropdown selector)					
Guts		Fins		Lugs	
Livers		Scales		(pectoral fin and bone)	
Heads		Skin		Belly flaps	
Tails		Cheeks		roe, milt)	
Shellfish e.g. body parts, heads, shell (crustacea only)					

What happens to the by-products (select yes / no from the dropdown selector)	
All by-products are retained on-board	
Part of them go overboard / the rest are retained onboard	
Approximately what % is retained on-board	*please specify*
They all go overboard into the sea	

Section 5. By-product utilisation

Which by-products are retained on board and utilised? (select yes / no from the dropdown)	
Guts	
Livers	
Heads	
Cheeks	
Tails	
Fins	
Scales	
Skin	
Lugs (pectoral fin and bone)	
Belly flaps	
Frames (backbone)	
Others	
heads, shell (crustacea	

For what purpose are the by-products utilised? (select yes / no from the dropdown)	
Fishmeal / marine ingredients	
Human consumption	
Bait	
Other use	*specify use*
Supplied to other processors after landing	*specify for what*

What methods are used to preserve the by-products onboard? (select yes / no from the dropdown)	
Fishmeal plant onboard	
Liver preservation	
Ensiling	
Freezing	
Chilling	
Other	*specify method*

What are the main reasons that prevent by-products being landed at present? (select yes / no from the dropdown)			
Lack of space on-board		Lack of market for the by-products	
Lack of suitable on-board treatment / storage		There is no demand for the by-products	
The crew has no time to process the by-products		It is not cost-effective	
Other reasons	*please specify*		

Section 6. Other information			
Any other comments, or anything else of relevance to this questionnaire?			
Please add any other comments here			
Do you have good examples of full catch utilisation	*Select*		
If yes please provide examples here. *Or please provide any other relevant information with the completed questionnaire*			
Would you be willing to be contacted for a potential case study?	*Select*	**Would you be willing to be contacted if we would like to discuss your answers in more detail?**	*Select*

Appendices

Questionnaire 2 – Comprehensive version issued online

By-products from processing fish at sea

This questionnaire is aimed at collecting information on processing seafood at sea and the generation of by-products at sea. We are looking for an overview of current practices in fisheries across the world.

For the purposes of this survey, by-products refer only to the parts of fish and shellfish removed during processing at sea that are not typically classed as the edible portion (i.e. fillet, loin, tail, meat etc).

Please DO NOT include any information on by-catch i.e. any part of the catch that is non-target and / or not retained.

*Required

1. Email *

2. Name of person completing this form; please provide first and last name. *

3. Which continent are you based in? *

   Tick all that apply.

   - [ ] Africa
   - [ ] Antarctica
   - [ ] Asia
   - [ ] Australia / Oceania
   - [ ] Europe
   - [ ] North America
   - [ ] South and Central America

4. Please indicate which fishery regions i.e. major FAO region your responses apply to *

   Tick all that apply.

   - [ ] ARCTIC SEA (Major Fishing Area 18)
   - [ ] Northwest Atlantic (Major Fishing Area 21)
   - [ ] ATLANTIC, NORTHEAST (Major Fishing Area 27)
   - [ ] ATLANTIC, WESTERN-CENTRAL (Major Fishing Area 31)
   - [ ] ATLANTIC, EASTERN CENTRAL (Major Fishing Area 34)
   - [ ] MEDITERRANEAN AND BLACK SEA (Major Fishing Area 37)
   - [ ] ATLANTIC, SOUTHWEST (Major Fishing Area 41)
   - [ ] ATLANTIC, SOUTHEAST (Major Fishing Area 47)
   - [ ] Atlantic, Antarctic (Major Fishing Area 48)
   - [ ] INDIAN OCEAN, WESTERN (Major Fishing Area 51)
   - [ ] INDIAN OCEAN, EASTERN (Major Fishing Area 57)
   - [ ] Antarctic and Southern Indian Ocean (Major Fishing Area 58)
   - [ ] PACIFIC, NORTHWEST (Major Fishing Area 61)
   - [ ] PACIFIC, NORTHEAST (Major Fishing Area 67)
   - [ ] PACIFIC, WESTERN CENTRAL (Major Fishing Area 71)
   - [ ] PACIFIC, EASTERN CENTRAL (Major Fishing Area 77)
   - [ ] PACIFIC, SOUTHWEST (Major Fishing Area 81)
   - [ ] PACIFIC, SOUTHEAST (Major Fishing Area 87)
   - [ ] Pacific, Antarctic (Major Fishing Area 88)

5. Main types of fish caught *

   Tick all that apply.

   - [ ] Demersal fish (whitefish, groundfish)
   - [ ] Pelagic fish
   - [ ] Shellfish (crustacea)
   - [ ] Shellfish (cephalopods)

6. What are the main species caught for commercial purposes. Please list up to 10 below, using a comma to separate each species. *

About the catch

This section is about the overall fishery and general practices.

7. For the species listed in the previous section, are any of these processed at sea? By 'processed' we mean headed, gutted, filleted, tailed etc. *

   Mark only one oval.

   - ( ) Yes
   - ( ) No

8. If you answered yes to the previous question, please explain which species are processed at sea. Please list them below using a comma to separate each species. *

9. For the species that are processed at sea, approximately what percentage (by weight) is processed? Please provide an overall figure or a species name followed by a % *

Processing at sea

This section is only relevant for fisheries where the catch (total catch or a proportion of) is processed on-board.

10. For species processed at sea, what type of processing is undertaken?

    Tick all that apply.

    - [ ] Gutting only
    - [ ] Heading only
    - [ ] Heading AND gutting
    - [ ] Production of fillets
    - [ ] Shellfish processing (shelling, cooking etc)
    - Other: [ ]

11. Are the by-products retained on-board the fishing vessel?

    Mark only one oval.

    - ( ) Yes - 100% of the by-products are retained
    - ( ) Partial - more than 50% of by-products are retained onboard
    - ( ) Partial - less than 49% are retained onboard
    - ( ) No - they are all discarded overboard

12. Which of the following by-products are retained on-board?

    Tick all that apply.

    - [ ] Guts
    - [ ] Liver
    - [ ] Heads
    - [ ] Cheeks
    - [ ] Tails
    - [ ] Fins
    - [ ] Scales
    - [ ] Skin
    - [ ] Belly flaps / other trimmings
    - [ ] Frames (backbone)
    - [ ] Shellfish (e.g. shell, body parts, viscera etc)
    - [ ] Cephalopods (e.g. viscera)
    - Other: [ ]

Questionnaire responses (collated)			
	Summarised responses (no's in brackets show no of responses)		
Regions	North America	Europe (2)	
	South America	Northwest Atlantic	
	Australia (2)	PNA Nations - Palau, FSM, RMI, Kiribati, Tuvalu, Nauru, Solomon Is, PNG and Tokelau	
FAO fishing regions	18, 21, 27, 51, 57, 58, 67, 71, 77, 81, 88		
Types of fish (main groups)	Demersal (6)		
	Pelagic (4)		
	Shellfish (4)		
Fish	Alaskan Pollock, Cod (Pacific, Atlantic), Haddock, Toothfish: *Dissostichus eleginoides, Dissostichus mawsoni, Sebastes* spp., *Hippoglossoides platessoides, Glyptocephalus cynoglossus, Limanda ferruginea, Reinhardtius hippoglossoides, Urophycis tennuis, Raya* spp. Toothfish, Icefish, Orange Roughy, Red snapper, Gold band snapper, Blue-eye trevalla, saddle tail snapper, Pacific Salmon, Pacific Herring, sharks, *Coryphaena hypurus*-Mahi Mahi, Tunas; skipjack tuna, yellowfin tuna, bigeye tuna, *Thunnus albacares, Thunnus obesus, Katsuwonus pelamis*.		
Shellfish	*Dosiducus gigas* - humboldt or giant squid; *Pandalus* spp. Banana prawns, Tiger Prawns, Endeavour prawns,		
For the species listed in the previous section, are any of these processed at sea?	Yes (6)	No (2) - but could be frozen	
For species processed at sea, what type of processing is undertaken?	Gutting (4)	Filleting (4)	
	Heading and gutting (5)	Freezing (3)	
Are by-products retained on-board?	Yes (3)	Partial (1)	No (4)
Which by-products are retained on-board?	Liver; Heads; Skin; Belly flaps / other trimmings; Frames (backbone)		
	Guts; Liver; Heads; Cheeks; Tails; Fins; Scales; Skin ;Belly flaps / other trimmings; Frames (backbone)		
	Cheeks, lugs (about 10% of total generated), skin, belly flaps, frames, heads		
Reasons why by-products are retained	Human consumption (2)	Fishmeal (1)	
Why by-products are not retained	Space, lack of on-board treatment/storage, crew has no time to process them, lack of market, limited/no demand, not cost-effective, short fishing season means we have to prioritise the more valuable parts of the catch (any and all of these apply)		

Appendices

Appendix III: Organisations and stakeholders contacted

At Sea Processors	N America; Antarctic; Europe; Asia; South Africa	Ten in total directly
Industry / Trade organisations	At Sea Processors Association	https://www.atsea.org
	European Association of Fish Producers Organisations (EAPO)	https://www.eapo.com
	European Fisheries Alliance	https://fisheriesalliance.eu
	Frozen at Sea Fillets Association	https://fasfa.co.uk
	Global Tuna Alliance	https://www.globaltunaalliance.com
	Iceland Ocean Cluster	https://www.sjavarklasinn.is/en/100-fish
	Norway Fisherman's Association	https://www.fiskarlaget.no/english
	Parties to the Nauru Agreement (PNA)	https://www.pnatuna.com
	Scottish Fishermen's Federation	https://www.sff.co.uk
	The South African Deep-Sea Trawling Industry Association, SADSTIA	https://www.sadstia.co.za
	Pelagic Freezer Trawler Association	https://www.pelagicfish.eu
RFMOs	North-East Atlantic Fisheries Commission (NEAFC)	http://www.neafc.org
	Northwest Atlantic Fisheries Organization (NAFO)	http://www.nafo.int
	South-East Atlantic Fisheries Organisation (SEAFO)	http://www.seafo.org
	Southern Indian Ocean Fisheries Agreement (SIOFA)	https://www.apsoi.org
	South Pacific Regional Fisheries Management Organisation (SPRFMO)	https://www.sprfmo.int
	Convention on Conservation of Antarctic Marine Living Resources (CCAMLR)	http://www.ccamlr.org
Others	Foundation – vessel listings	Global
	Fishing Index	Global
	Global Vessel Monitoring	Global
	IMO	Global
	Foundation for Fishers	Global
	Association of Sustainable Fisheries	Global
	World Maritime University	Global

Appendix IV: Motorised fishing vessels >24m LOA by country (continent)

The countries or areas listed in this table are those with capture production of 200 000 tonnes or more in 2019. (FAO, 2020) (Food and Agriculture Organisation, 2021)

Africa	No. of powered fishing vessels	Americas	No. of powered fishing vessels	Asia	No. of powered fishing vessels	Europe	No. of powered fishing vessels	Oceania	No. of powered fishing vessels	
Morocco	20329	Peru	4172	China	468312	Norway	5980	New Zealand	1135	
Nigeria	78144	USA	75231	Indonesia	460658	Iceland	2003	Papua New Guinea	588	
Mauritania	3816	Chile	13544	India	143020	Spain	8882			
Uganda	6795	Mexico	63185	Russia	1534	Faroe Isl.	156			
Senegal	0	Argentina	4572	Vietnam	34563	Denmark	2073			
Tanzania	33755	Canada	16912	Japan	225226	UK	6199			
Namibia	180	Brazil	21732	Philippines	183998	France	6223			
South Africa	1780	Ecuador	10704	Myanmar	17288	Turkey	17497			
Angola	2046	Venezuela	43207	Bangladesh	33093	Netherlands	836			
Egypt	3840	Greenland	1851	Thailand	11237	Georgia	26			
Ghana	11101	Panama	3554	Malaysia	47790	Germany	1309			
Mozambique	729	Kiribati	1218	South Korea	65061	Poland	760			
Guinea	1392	Belize	561	China, Taiwan	21373	Ireland	2036			
Cameroon	8669			Cambodia	78172					
Sierra Leone	7533			Iran	12275					
Congo Dem R	15885			Oman	25206					
				Sri Lanka	31376					
				Pakistan	10232					
				Korea D P Rp	0					
TOTAL	**195994**		**260443**		**1870414**		**53980**		**1723**	
% of motorised fleet that is >24m LOA	**4.1**		**1.7**		**3.2**		**5.8**		**4.9**	
Estimated no of vessels >24M LOA	**8036**		**4428**		**59853**		**3131**		**84**	**75532**
% of total no of motorised fleet	**10.6**		**5.9**		**79.2**		**4.1**		**0.1**	**100.0**
% applied to FAO estimate of 67,800	**7213**		**3974**		**53726**		**2810**		**76**	**67800**

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Appendix V: Vessel size profiles by country in 2018 (OECD, 2022)																					
Country	**Vessel size LOA Unknown**	**Country**	**Vessel size 0-5.9m**	**Country**	**Vessel size 6-11.9 m**	**Country**	**Vessel size 12-17.9 m**	**Country**	**Vessel size 18-23.9 m**	**Country**	**Vessel size 24-29.9 m**	**Country**	**Vessel size 30-35.9 m**	**Country**	**Vessel size 36-44.9 m**	**Country**	**Vessel size 45-59.9 m**	**Country**	**Vessel size 60-74.9 m**	**Country**	**Vessel size 75 m and over**
Japan	230504	Australia	1	Australia	10	Australia	59	Australia	157	Australia	37	Australia	12	Australia	3	Australia	4	Australia	2	Denmark	6
Korea	817	Denmark	796	Belgium	1	Belgium	4	Belgium	29	Belgium	5	Belgium	11	Belgium	18	Denmark	10	Denmark	6	France	20
New Zea-land	4	Finland	1661	Canada	9475	Canada	8667	Denmark	60	Canada	233	Canada	49	Canada	6	France	6	France	6	Germany	7
China (People's Republic of)	682416	France	707	Denmark	976	Denmark	217	Finland	9	Denmark	19	Denmark	15	Denmark	17	Germany	4	Iceland	24	Iceland	11
Indonesia	719769	Germany	525	Finland	1521	Finland	34	France	268	Finland	4	Finland	7	Finland	9	Iceland	31	Ireland	6	Italy	1
Chinese Taipei	371	Greece	5160	France	4784	France	425	Germany	87	France	97	France	43	France	23	Ireland	15	Korea	70	Korea	16
		Iceland	1	Germany	528	Germany	144	Greece	241	Germany	13	Germany	13	Germany	14	Italy	5	Mexico	30	Mexico	7
		Ireland	612	Greece	8913	Greece	443	Iceland	24	Greece	146	Greece	28	Greece	3	Korea	207	New Zealand	13	Netherlands	7
		Italy	2465	Iceland	878	Iceland	108	Ireland	80	Iceland	38	Iceland	9	Iceland	24	Mexico	12	Norway	76	New Zealand	9
		Korea	11929	Ireland	1140	Ireland	91	Italy	716	Ireland	65	Ireland	13	Ireland	10	Netherlands	4	Portugal	5	Norway	17
		Mexico	19501	Italy	6179	Italy	2381	Korea	1631	Italy	263	Italy	28	Italy	21	New Zealand	7	Spain	15	Poland	2
		Netherlands	108	Korea	43541	Korea	6652	Mexico	1278	Korea	579	Korea	248	Korea	216	Norway	47	Sweden	2	Portugal	6
		New Zea-land	354	Mexico	55998	Mexico	459	Netherlands	193	Mexico	166	Mexico	28	Mexico	4	Portugal	3	Turkey	2	Spain	25
		Norway	497	Netherlands	235	Netherlands	50	New Zea-land	115	Netherlands	55	Netherlands	60	Netherlands	121	Spain	35	United Kingdom	10	Turkey	0
		Poland	124	New Zea-land	311	New Zea-land	312	Norway	115	New Zealand	23	New Zealand	10	New Zealand	10	Sweden	3	Argentina	65	United Kingdom	10
		Portugal	3511	Norway	4450	Norway	660	Poland	57	Norway	66	Norway	39	Norway	58	Turkey	37	Colombia	11	Argentina	8
		Spain	2757	Poland	541	Poland	56	Portugal	154	Poland	43	Poland	3	Poland	1	United Kingdom	7	Costa Rica	1	Colombia	2
		Sweden	236	Portugal	3611	Portugal	399	Spain	652	Portugal	126	Portugal	27	Portugal	9	Argentina	80	Estonia	4	Costa Rica	0
		Turkey	2406	Spain	3810	Spain	1053	Sweden	40	Spain	382	Spain	164	Spain	83	Colombia	13	Latvia	2	Latvia	2
		United Kingdom	1603	Sweden	826	Sweden	83	Turkey	401	Sweden	10	Sweden	9	Sweden	6	Costa Rica	0	Lithuania	2	Lithuania	4
		Argentina	9	Turkey	11378	Turkey	674	United Kingdom	221	Turkey	219	Turkey	130	Turkey	105	Estonia	1	Chinese Taipei	114	Chinese Taipei	15
		Costa Rica	711	United Kingdom	3541	United Kingdom	454	Argentina	80	United Kingdom	126	United Kingdom	41	United Kingdom	33	Latvia	5				175
		Estonia	1151	Argentina	289	Argentina	168	Colombia	41	Argentina	85	Argentina	51	Argentina	68	Lithuania	5				
		Latvia	471	Colombia	8	Colombia	22	Costa Rica	127	Colombia	7	Colombia	5	Colombia	11	Chinese Taipei	223				
		Lithuania	74	Costa Rica	1989	Costa Rica	310	Estonia	6	Costa Rica	16	Costa Rica	0	Costa Rica	1						
		Slovenia	56	Estonia	470	Estonia	11	Latvia	3	Estonia	18	Estonia	2	Latvia	1						
		Chinese Taipei	2262	Latvia	141	Latvia	10	Lithuania	4	Latvia	38	Latvia	3	Lithuania	2						
				Lithuania	28	Lithuania	1	Slovenia	1	Lithuania	22	Lithuania	2	Chinese Taipei	88						
				Slovenia	62	Slovenia	15	Chinese Taipei	1923	Chinese Taipei	291	Chinese Taipei	106								
				Chinese Taipei	12231	Chinese Taipei	4284														
TOTALS	**1633881**		**55674**		**162647**		**23425**		**6608**		**2715**		**987**		**794**		**536**		**466**		**350**
										TOTAL >25m	**5848**										

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Appendix VI: Detailed yield data - Compiled from multiple references

Species / group	'Guts'				Head:				Head and guts: % live wt (fixed Ave)	Skinned fillets			
	% live wt (min)	% live wt (max)	% live weight (fixed Ave)	% live weight (Ave)	% live wt (min)	% live wt (max)	% live wt (fixed Ave)	% live wt (aver)		(skin off) (min)	(skin off) (max)	(skin off) (fixed Ave)	(skin off) (Ave)
Roundfish general (Cod (FAO)©)	8	22	16	15	9	20	21	14.5	37	?	?	36	?
Tuna (general)			8				18		26	30	50	50	30
Flatfish (general)	4	18	9	11	18	25		21.5		34	46	35	40
squid										60	80		70

Appendix VII: Detailed nutritional composition data - PROXIMATE

	Moisture	Protein	Fat	Ash	Format
	% Wet weight				
Cod					
Waste from filleting	79.4-79.5	14.1-14.3	1.7-2.0	3.8-3.9	All by-products
cod skin	78.8	20.3	0.6	2.6	Skin
Cod roe	71.5	23.5	2.5	1.4	Roe
cod trimmings	85.1	14.9	0.6	0.8	Trimmings (flesh)
Pollock					
Waste from filleting	81.3-82	11.3-12.5	1.9-3	3.6-3.7	All by-products
Halibut					
heads	65.5	11.6	16.2	4.1	Head
Salmon					
Heads	67.3	13.3	15.8	4.2	Heads
Viscera	80.5	16.2	2.5	1.6	Viscera
Crab					
Tanner crab	76.7	8.9	1.1	9.2	Carapace and viscera
King crab	71.7	13.8	1.6	10.3	Carapace and viscera

Characterisation of Alaska Seafood Waste, University of Alaska, 1988

	Protein (% of wet weight)					
	Head	Backbone / frame	Off-cuts	Skin (including belly flap)	Milt	Viscera
Cod			13-23			9-13
Saithe			15-19			12-19
Haddock			15-18			7-11
Tusk			17-23			3-12
Ling			15-20			8-12
Carp, wild			14-22		14-27	15-23
Atlantic salmon	11-13	10-15		8-12		5-7
Herring	13.1				18	

Maximising the Value of Marine By-Products, Shahidi et al, 2006

	Moisture	Protein	Fat	Ash
	Pollock by-product composition (calculated: adjusted 8% moisture (values in %)			
Pollock				
Whole fish	8	65.7	15.5	10.8
Fillets	8	84.9	1.9	5.2
Head	8	67.4	5.2	19.4
Frame	8	73.6	3.9	14.5
Viscera	8	41.2	47.2	3.6
Skin	8	87.5	1.7	2.8

Advances in Seafood By-products, Alaska Sea Grant College Program, 2003

Fish bone composition (lipid free dm)	Protein (g/100 g)	Ash (g/100g)
Cod	39	58
Salmon	47	50
Herring	44	51
Mackerel	59	44

Fisheries and Aquaculture Department (FI) in FAO

Components	Whitefish offal
Water	80%
Protein	15%
Ash	4.5%
Fat	0.5%

Taken from Torry Research Station Advisory Note on Fish Silage

Composition of fish processing waste

Components (%)	Cod offals
Moisture	77.61 +/- 0.35
Crude protein	14.3 +/- 0.61
Lipid	4.3 +/- 0.78
Ash	3.95 +/- 0.25
Calorific value (kJ/100g)	431 +/-43
Protein efficiency ratio (calculated)	2.31 - 2.33

Taken from Seafoods Chemistry, Processing Technology & Quality - Edited by F. Shahidi & JR Botta

	Value	DM
Crude protein	%	57.92 ± 5.26
Fat	%	19.10 ± 6.06
Crude fibre	%	1.19 ± 1.21
Ash	%	21.79 ± 3.52
Calcium	%	5.80 ± 1.35
Phosphorous	%	2.04 ± 0.64
Potassium	%	0.68 ± 0.11

	Value	DM
Sodium	%	0.61 ± 0.08
Magnesium	%	0.17 ± 0.04
Iron	ppm	100.00 ± 42.00
Zinc	ppm	62.00 ± 12.00
Manganese	ppm	6.00 ± 7.00
Copper	ppm	1.00 ± 1.00

Ref: Ghaly, A.E (et al)(2013)

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Cyprinus carpi (freshwater)					
Scales	**Moisture**	**Protein**	**Lipid**	**Ash**	**Carbohydrate**
1 (300–400.03 g)	73.4±1.21a	22.1±0.75a	1.9±0.24a	3.89±0.65a	1.38±0.40a
2 (310–498 g)	71.2±1.30b	23.5±0.70b	2.1±0.09a	4.98±0.45b	1.42±0.35b
3 (601–800 g).	68.5±1.70c	23.9±0.85c	2.3±0.40b	5.6±0.50c	1.51±0.23b
Fins					
1 (300–400.03 g)	55.8±1.01a	13.9±0.52a	3.6±0.16a	8.2±0.98a	2.5±0.23a
2 (310–498 g)	53.2±0.85b	17.4±0.66b	4.9±0.42b	9.1±1.22b	1.7±0.29b
3 (601–800 g).	50.3±1.25c	19.00±0.70c	6.11±0.48b	10.6±1.26c	2.3±0.22a
Bones					
1 (300–400.03 g)	53.6±0.84a	25.9±0.90a	5.9±0.15a	1.48±0.10a	1.9±0.03a
2 (310–498 g)	49.1±1.09	26.1±1.00a	6.7±0.26b	1.35±0.18b	1.7±0.02b
3 (601–800 g).	46.40±0.62	27.3±1.20a	7.00±0.33c	1.70±0.32c	1.9±0.05a

a, b, c refer to mean in the same column for each species followed by different letters. a,b,c are significantly different according to P-value≤0.05 ± standard deviation, while the same letters are not significant different.

Ref: Afrah A. Maktoof et al (2020)

Dried powder prepared tuna processing by-products and burrito.				
Parameter	**Tune trimmings**	**Tuna frames**	**Tuna gills**	**Burrito**
Moisture (g/100 g)	4.8 ± 0. 0.13b	8.4 ± 0.10d	6.8 ± 0.24c	3.5 ± 0.03a
Water Activity (aw)	0.6 ± 0.01a	0.65 ± 0.3a	0.62 ± 0.01a	0.6 ± 0.00a
Ash (g/100 g)	3.4 ± 0.78a	44.11 ± 0.03d	42.99 ± 0.05c	14.0 ± 0.13b
Fat (g/100 g)	5.7 ± 0.12c	11.3 ± 0.03a	4.5 ± 37b	11.1 ± 14a
Protein (g/100 g)	80.71 ± 0.16d	28.66 ± 0.16a	38.29 ± 0.20b	70.4 ± 0.11c
Carbohydrate (including fibre) (g/100 g)	5.39 ± 0.24c	7.53 ± 0.09a	7.42 ± 0.37a	1.0 ± 35b
Energy (Kcal/100 g)	395.7 ± 1.45d	242.5 ± 0.14b	223.3 ± 1.11a	381.5 ± 3.25c
Phosphorus (mg/100 g)	600.9 ± 26.66b	1010.2 ± 12.16c	1071,8 ± 3.14d	93.71 ± 4.99a
Calcium (mg/100 g)	1066.5 ± 24.20a	13184.3 ± 56.53c	15469.3 ± 4.80d	2586.63 ± 4.26b

Results are presented as means and standard deviations. Analysis of variance (ANOVA) and Duncan test were used to significant differences between samples (P < 0.05). Means with the same superscripts are not significantly different from each other.

Lawrence Abbey et al

Minerals									
	K	**Na**	**Cu**	**Zn**	**Mg**	**Mn**	**Ca**	**Fe**	
	mg/kg wet weight								**Format**
Cod									
fillet	2.41-3.31	1.2-1.42	0.1 - 1.02	10.43 - 12.07	2.34 - 2.93	1.62-1.63	3.8-3.96	2.04-6.88	All by-products
cod skin	1.29	0.24	0.48	1.15	1.69	2.25	3.15	2.07	Skin
Cod roe	2.41	1.01	0.87	28.29	0.48	0.34	0.1	6.43	Roe
cod trimmings	2.35	0.51	1.57	6.49	1.82	0.28	1.89	3.11	Trimmings (flesh)
Pollock									
Waste from filleting	1.99-2.34	1.71-2.27	0.47-1.33	13.36-16.86	3.46-4.02	0.82-0.94	3.98-5.15	8.12-8.41	All by-products
Halibut									
heads	0.82	0.12	0.37	4.53	1.09	0.19	8.8	2.04	Head
Salmon									
Heads	1.66	1.94	1.8	24.52	3.37	0.61	35.23	6.77	Heads
Viscera	0.96	0.26	44.3	176.28	2.07	0.54	13.37	6.88	Viscera
Crab									
Tanner crab	0.28	1.63	1.02	37.75	22.12	1.62	271.46	24.04	Carapace and viscera
King crab	1.54	4.93	2.21	22.92	23.09	2.15	229.16	11.94	Carapace and viscera

Characterisation of Alaska Seafood Waste, University of Alaska, 1988

	Ca	**Mg**	**Na**	**P**	**K**	**Cd**	**Fe**	**Pb**	**Zn**
	% dry matter			**mg/kg dry matter**					
Pollock									
Whole fish	2.5	0.15	0.89	0.9	1.1	1.1	43.4	<2	57.5
Head	6.6	0.22	1.3	3.6	0.72	<0.03	47.6	<2	68.6
Viscera	0.27	0.07	0.37	0.78	0.62	0.62	74.4	<2	63.5
Frame	5.9	0.2	0.82	3.5	1.1	<0.03	36.7	<2	61.4
Skin	0.63	0.07	0.34	0.53	0.14	<0.03	26.4	<2	29.2
Fillets	0.13	0.15	0.67	0.98	1.6	<0.03	10.2	<2	21.6

Advances in Seafood By-products, Alaska Sea Grant College Program, 2003

Mean data for the nutrient composition of by-product samples (head, gills, intestines, trimmings, bones, skin) of meagre and gilthead sea bream fishes in two different size classes (large and small).

By-Product Nutrient Composition

	(g/100 g) *	Head				Gills				Intestines				Trim				Bones				Skin			
		Large		Small		Large		Small		Large		Small		Large		Small		Large		Small		Large		Small	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Meagre	Moisture	64	0.5	68.9	0.7	68.3	0.2	74.3	0.4	73	0.2	59.2	0.4	63.1	0.7	57	0.1	63.2	0.7	40.6	0.2	58.4	0.3	65.3	0.2
	Ash	20.95	0.37	21.27	1.04	15.59	0.98	19.18	0.32	4.77	0.08	2.25	0.05	49.12	1.91	48.51	2.55	21	0.58	23.3	1.23	20.24	0.53	15.23	1.06
	Protein	40.41	0.16	47.5	1.25	45.62	0.16	48.46	0.32	59.62	0.08	29.79	0.64	45.87	0.91	45.98	1.92	32.07	0.25	36.41	0.13	75.16	1.87	75.15	0.03
	Fat	28.88	1.6	23.34	0.74	19.71	1.33	21.31	0.45	17.09	0.19	54.05	4.94	3	1.5	4.35	0.69	34.96	0.1	31.07	2.1	6.12	0.42	9.61	1.6
	Carbo-hydrates	9.76	1.65	7.89	1.78	19.08	1.66	11.05	0.63	18.52	0.22	13.91	4.98	2.01	2.59	1.16	3.27	11.97	0.64	9.22	2.44	1.01	0.01	0.99	0.01
Gilthead Sea Bream	Moisture	57.3	0.7	62.4	0.2	66.6	0.3	62.9	0.8	67.1	1	57.15	0.5	48.6	0.1	53.1	0.2	53.3	0.7	74.5	0.8	53	0.5	61.2	0.1
	Ash	18.11	1.24	21.39	1.33	16.6	0.4	17.49	0.3	3.57	0.06	2.62	0.07	45.76	2.29	47.26	0.73	26.62	0.1	27.7	0.58	6.02	0.17	4.36	0.17
	Protein	32.4	0.45	37.19	0.67	31.49	0.42	38.5	1.47	37.23	0.75	26.87	0.35	41.85	1	45.1	2.3	34.02	0.98	40.74	1.57	43.16	0.89	49.67	0.11
	Fat	37.08	4.19	28.76	0.47	37.46	1.16	26.69	0.23	43.19	0.35	55.12	0.98	5.45	0.09	4.09	0.33	30.56	0.11	21.47	0.54	46.39	3.45	45.94	0.54
	Carbo-hydrates	12.41	4.39	12.66	1.56	14.45	1.3	17.32	1.52	16.01	0.83	15.39	1.04	6.94	2.5	3.55	2.44	8.8	0.99	10.09	1.75	4.43	3.56	0.03	0.02

* ash, protein, fat, and carbohydrate contents are expressed on a dry weight basis; carbohydrates were calculated by difference; no statistically significant differences were observed between the different by-products, either between fish species or size classes.

Aikaterini Kandyliari et al (2020)

Appendices

By-product nutrient composition

	(mg/g)	Head				Gills				Intestines				Trim				Bones				Skin			
		Large		Small		Large		Small		Large		Small		Large		Small		Large		Small		Large		Small	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Meagre	Calcium (Ca)	5.02	0.72	8.59	1.13	5.88	0.23	6.8	0.12	0.61	0.04	0.58	0.1	12.82	0.34	46.58	1.34	6.39	0.93	9.58	0.57	5.59	0.71	3.9	0.08
	Sodium (Na)	4.07	0.37	4.92	0.56	5.52	0.13	5.92	0.27	2.53	0.12	2.12	0.57	5.87	0.99	3.72	0.43	3.46	0.11	2.76	0.73	4.42	0.28	3.15	0.17
	Potassium (K)	6.31	1.05	8.3	0.87	8.55	1.06	9.34	0.77	8.92	1.03	4.86	1.13	6.92	1.02	6.65	0.66	7.62	0.24	8.92	0.23	8.46	1.03	9.33	1.12
	Magnesium (Mg)	0.24	0.19	1.34	0.44	1.37	0.17	3.52	0.82	2.51	0.55	1.49	0.67	0.71	0.04	2.46	0.25	0.67	0.13	0.45	0.12	0.43	0.03	0.76	0.32
	% RDA/AI (Ca) *	50		86		59		68		6		6		128		466		64		96		56		39	
	% RDA/AI (Na) *	27		33		37		39		17		14		39		25		23		18		29		21	
	% RDA/AI (K) *	13		18		18		20		19		10		15		14		16		19		18		20	
	% RDA/AI (Mg) *	8		42		43		110		78		47		22		77		21		14		13		24	
Gilthead Sea Bream	Calcium (Ca)	8.59	0.43	5.62	1.02	4.52	0.72	7.59	0.33	0.24	0.09	0.67	0.25	42.38	0.11	11.49	0.45	9.23	0.34	7.92	1.1	2.1	0.92	0.5	0.02
	Sodium (Na)	3.68	0.21	3.28	0.21	4.26	0.82	4.54	0.72	3.01	0.79	2.39	1.01	6.81	0.35	6.08	0.26	3.43	0.14	3.79	0.99	3.52	0.13	1.34	0.22
	Potassium (K)	6.47	0.92	6.4	1.02	7.04	0.11	8.16	0.13	4.65	0.15	7.83	1.73	7.09	0.13	8.09	1	6.92	0.88	8.35	0.37	7.44	0.32	8.66	0.64
	Magnesium (Mg)	0.86	0.43	0.28	0.29	0.64	0.31	2.49	0.46	1.61	0.17	2.84	0.12	3.34	1.04	0.77	0.25	0.33	0.06	0.3	0.09	0.58	0.36	2.1	0.03
	% RDA/AI (Ca) *	86		56		45		76		2		7		424		115		92		79		21		5	
	% RDA/AI (Na) *	25		22		28		30		20		16		45		41		23		25		23		9	
	% RDA/AI (K) *	14		14		15		17		10		17		15		17		15		18		16		18	
	% RDA/AI (Mg) *	27		9		20		78		50		89		104		24		10		9		18		66	

* Mineral concentration was calculated as mg/g of dry matter; RDA/AI percentages for the content of 100 g of dried sample were calculated based on the following values: 1000 mg for Ca, 4700 mg for K, 329 mg for Mg, and 1500 mg for Na [31].

Aikaterini Kandyliari et al (2020)

Appendices

Fish bone composition (lipid free dm)				
Content	Cod	Salmon	Herring	Mackerel
Protein (g/100 g)	39	47	44	59
Ash (g/100g)	58	50	51	44
Calcium (g/100g)	19	14	16	14
Iron (mg/100g)	5	3	6	7
Zinc (mg/100)	10	23	19	13
Iodine (mg/100g)	0.4	0.3	0.1	0.2

Micronutrients of tuna back bone powder	
mg/100mg	
Calcium	700
Zinc	5.6
Iron	8.9
Selenium	0.02
EPA+DHA	150
Fisheries and Aquaculture Department (FI) in FAO	

Amino acids	Alanine	Arginine	Aspartic acid	Cysteine	Glutamic acid	Glycine	Hydroypro-line	Isoleucine	Leucine	Lysine	Methio-nine	Phenylala-nine	Proline	Serine	Valine	Histadine	Theonine	Tyrosine
	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight	mg/kg wet weight
Cod																		
fillet	8.6	15.1	9	1.7	13.7	15.9	4.2	4.7	10	12.2	5.1	5.7	10.5	5.6	5.2			
cod skin	8.9	14.7	7.8	1.5	12	22.2	5.4	3.9	8.3	7.8	3.8	5	13.7	5.9	4.4			
cod trimmings	6.9	13.8	9.1	1.8	14.7	6.9	-	5.2	11	15.6	5.7	5.8	6	5.3	5.2			
Pollock																		
Waste from filleting	6.1	9.5	5.2	1.3	11.4	11.4	1.5	2.1	7.3	10.5	3.6	3.5	5.8	3.2	3.3			
Halibut																		
heads	10.5	11.3	11.6	-	12	21.6	-	4.3	8.3	8.8	3.8	4.5	11.1	8.6	6.5	2.6	5.4	3.2
Salmon																		
Heads	8.8	8.6	10.5	-	14.7	16.1	-	4.3	7.8	7.9	3.2	4.2	4.3	6.1	6.5	2.9	4.9	3.2
Viscera	8.7	10.8	12	-	16.3	8.8	-	6.2	11.4	11.9	3.3	5.6	7	6.8	9.1	2.9	6.5	5.1
Crab																		
Tanner crab	4.3	4.3	7.3	-	8.7	5.3	-	2.8	4.4	3.4	1.2	3.3	5.2	3.8	4.61	1.7	3.7	2.9
King crab	4.9	6.4	9.5	-	11.8	6.4	3	4.1	6.3	4.8	1.8	4.5	5.5	5.4	5.3	3	4.4	4.3
Pollock																		
Whole fish	7.68	6.26	7.97	1.12	8.63	14.41	2.66	4.39	7.7	5.5	2.94	4.82	5.21	7.03	5.77	3.5	5.41	
Head	7.96	5.86	7.8	0.92	8.09	17.46	2.58	3.87	6.88	5.72	2.76	4.47	5.9	7.01	5.27	2.6	4.87	
Frame	7.48	5.48	7.53	0.96	7.92	16.88	2.75	3.95	6.99	6.31	2.96	5.07	5.63	6.57	5.73	2.98	4.82	
Viscera	7.72	3.81	8.56	1.23	7.46	10.63	3.15	4.8	8.35	5.59	2.83	5.76	6.48	6.78	6.24	4.79	5.82	
Skin	8.34	3.93	6.85	0.27	6.53	33.69	2.03	2.19	3.98	3.4	2.11	3.01	8.55	6.58	3.8	1.7	3.05	
Fillets	7.71	5.38	7.06	1.26	9.18	11.47	3.08	4.55	7.83	6.38	3.44	5.88	5.21	5.53	6.29	4.55	5.2	

Appendices

Fatty Acids

Fatty acid content (g/100 g) of the pooled by-products from meagre and gilthead sea bream fishes. Aikaterini Kandyliari *et al (2020)*

	Meagre (*Argyrosomus regius*)		Gilthead Sea Bream (*Sparus aurata*)		
Fatty Acids	**Mean**	**SD**	**Mean**	**SD**	**p**
14:0	0.63	0.08	1.4	0.27	<0.05
15:0	0.06	0	0.1	0.01	<0.05
16:0	3.19	0	4.85	0	0.08
16:1	0.94	0	2.23	0	<0.001
17:0	0.05	0.01	0.08	0.02	0.19
18:0	0.71	0.01	0.78	0.05	0.91
18:1	6.63	0	11.34	0.01	<0.05
18:2 n-6	2.6	0.12	4.24	0.18	0.11
18:3 n-6	0.03	0.37	0.07	1.06	<0.001
18:3 n-3	0.47	0	0.81	0.02	<0.05
18:4 n-3	0.15	0	0.31	0.02	<0.05
20:0	0.07	0.07	0.09	0.21	0.39
20:1 n-9	1.14	0.03	1.53	0.09	0.32
20:2 n-9	0.02	0.01	0.09	0.02	<0.001
20:2 n-6	0.13	0.13	0.2	0.37	0.12
20:3 n-6	0.04	0	0.09	0.03	<0.05
20:3 n-3	0.12	0.02	0.14	0.04	0.35
20:4 n-6	0.04	0.01	0.09	0.02	<0.001
20:4 n-3	0.1	0.03	0.26	0.02	<0.001
20:5 n-3	0.23	0.01	0.42	0.02	<0.05
22:1	1.09	0.04	1.3	0.13	0.58
22:2 n-6	-	-	0.03	0	<0.05
23:0	0.04	0.01	0.1	0.02	<0.001
22:5 n-3	0.26	0.04	0.7	0.23	<0.001
22:6 n-3	0.3	0.05	0.53	0.15	<0.05
Total Fatty Acids	19.15	2.62	31.86	7.85	<0.05
SFA	4.84	0.69	7.45	1.71	0.05
PUFA	4.6	0.67	8.16	2.11	<0.05
MUFA	9.71	1.27	16.25	4.05	<0.05

Fatty acids are expressed as g/100 g of the lyophilized sample; p presents the differences between the two fish species.

Crustacea – various nutritional information

Reference: Seafish (2008)

Determinant	**Unit**	**Crab (brown)**				**Shrimp**
				clean / crushed	**units based on dry matter**	
PH		7.4				
Dry matter	g/kg	579	40.3 % wt/wt		53%	
Total N	g/kg	30.4	46.3		34.9	
Ammonium N	g/kg	4.53	1.22		3.96	
Total P	g/kg	1.6	7.82		11.6	
Total K	g/kg	2.9	2.27		2.01	
Total Mg	g/kg	7.4	10.1		13.2	
Total lead	mg/kg	<5.0		4.8		
Total nickel	mg/kg	<1.0		1.9		
Total zinc	mg/kg	18.3		52.7		
Total cadmium	mg/kg	<0.10		0.58		
Total chromium	mg/kg	1.51		26.9		
Total copper	mg/kg	4.35		14.4		
Organic carbon	% wt/wt	11.8				
Total sulphur	Mg/kg	3000	5310			
Total magnesium	mg/kg	10100	5930			
Organic matter	% wt/wt	21.9*	20.1		39	
Neutralising value	% wt/wt	10	3			
Moisture content	%	42.5		26.4		
Crude protein	(% dry wt)	19.08				
Lipid	(% dry wt)	0.85				8.39
Ash	(% dry wt)	30.68				29.03
Chitin	(% dry wt, deproteinised shells)	29.6				40.4
Carotenoids	(ug/g)	139.9				147.7
Flavorants	(% of protein)	1.4				1.58
Calcium as Ca	%	27.4	72.1			
Calcium as CaCO3	mg/kg	68.5	44.12			
Arsenic	mg/kg			14.4		
Energy	kJ/100g					
Energy	kcal/100g					
Protein	g/100g					41.7
Fat	g/100g					5.2
Crude fat	% composition					
Ash	g/100g					28.3
Moisture content	g/100g					9.6
Total carbohydrate	g/100g					
Free astaxanthin	mg/kg					2.2
Astaxanthin esters	mg/kg					136 - 154
Non chitin nitrogen	% of total nitrogen					
Minerals	% composition					

** Calculated from organic carbon x 1.724*

Appendices

Seafood by-product composition information (various species and determinants) *Reference: Seafish (2004)*					
Determination	**Units**	**Whitefish**	**Pelagic**	**Fish & Shellfish**	**Mixed seafood**
pH		7.1	6.8	7.8	7.4
Oven Dry Matter	g/kg	226	393	413	514
Total Nitrogen (Kjeldahl)	g/kg, 100% DM	134	99.1	30.9	26.6
Total Phosphorus	mg/kg, 100% DM	44200	12600	14000	3050
Total Potassium	mg/kg, 100% DM	11400	3720	3120	1790
Loss on Ignition	%wt/wt, 100% DM	74	91.9	76.4	21.9
Conductivity 1:10 extract	pS/cm 2000	2560	3570	3020	2390
Oil acid hydrolysed	%, 100% DM	3	403	568	1.4
Organic Carbon	% m/m, air dried	34.2	55.7	41.5	10.5
Total Magnesium	mg/kg, 100% DM	1850	931	2090	2120
C:N Ratio		3	6	13	4

		Cod	Haddock	Mackerel	Nephrops	Crab	Whelks	Mussels
Determination	**Units**							
pH		7	6.8	6.8	7.8	7.4	7.8	5.1
Oven Dry Matter	g/kg	229	228	402	299	579	778	607
Total Nitrogen (Kjeldahl)	g/kg, 100% DM	148	147	77.8	43.6	30.4	11.8	26.3
Total Phosphorus	mg/kg, 100% DM	44900	44000	27600	15800	16000	1070	912
Total Potassium	mg/kg, 100% DM	9980	11800	4000	2890	2900	1300	1320
Loss on Ignition	%wt/wt, 100% DM	72.5	72.9	84.6	52.2	34.3	10.1	18.1
Conductivity 1:10 extract	pS/cm 2WC	1890	2370	4990	1820	4090	1650	1280
Total Ash	%, 100% DM	27.5	27.1	15.5	47.8	65.7	89.9	81.9
Oil (acid hydrolysed)	%, 100% DM	2.9	1.7	39.5	<0.1	0.3	0.3	
Organic Carbon	% m/m, air dried	33.3	33.9	52.6	17	11.8	3.64	6.86
Total Magnesium	mg/kg, 100% DM	1700	1940	1690	7280	7420	1080	805
Total Lead	mg/kg, 100% DM	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Total Nickel	mg/kg, 100% DM	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Total Zinc, mg/kg	mg/kg, 100% DM	60	65.2	77.2	17.8	18.3	546	9.13
Total Cadmium	mg/kg, 100% DM	0.11	<0.10	0.36	<0.10	<0.10	4.44	<0.10
Total Chromium	mg/kg, 100% DM	2.04	2.29	1.3	1.9	1.51	1.74	<0.20
Total Copper	mg/kg, 100% DM	1.78	2.8	2.68	4.36	4.35	17.5	1.63
Ammonium-N	mg/kg, 100% DM	13400	18600	7950	7890	4530	3190	2560
C:N Ratio		2	2	7	4	4	3	3

Determination (Units)	White Fish A	White Fish B	White Fish C	Mackerel A	Mackerel B	Mackerel C
* pH	7.2	7.2	7.1	6.8	6.8	6.8
* Oven Dry Matter, g/kg	224	221	244	414	428	407
* Total Nitrogen (Kjeldahl), g/kg, 100% DM	114	87.1	121	57.1	55	59.1
Total Phosphorus, mg/kg, 100% DM	58600	32600	42300	10400	14400	13300
Total Potassium, mg/kg, 100% DM	11200	13000	10300	4850	3350	4670
* Loss on Ignition, % wt/wt, 100% DM					92.5	
*Total Ash %, 100% DM	27.2	24.3	22.7	7.2		8.3
* Organic Carbon, % rn/in, air dried	29.2	38.6	39.5	56.7		52.9
Total Magnesium, mg/kg, 100% DM	2140	1810	1750	1140	1110	1180
Total Lead, mg/kg, 100% DM	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Total Nickel, mg/kg, 100% DM	<1.0	< 1.0	<1.0	< 1.0	< 1.0	< 1.0
Total Zinc, mg/kg, 100% DM	61.3	56.3	60.7	52	43.8	50.2
Total Cadmium, mg/kg, 100% DM	<0.25	<0.25	<0.25	0.53	<0.25	0.72
Total Chromium, mg/kg, 100% DM	2.48	1.45	1.97	< 1.00	< 1.00	< 1.00
Total Copper, mg/kg, 100% DM	1.51	1.74	1.33	2.35	2.8	2.71
Total Mercury, mg/kg, 100% DM	0.13	0.09	0.09	0.13	0.04	0.06
Ammonium-N, mg/kg, 100% DM	15400	19500	8000	6470	7090	8120
*C:N Ratio	3	4	3	10	10	9

Appendices

	Whelks	Nephrops	Crab	Mussels	Mackerel	White Fish
Determination (units)						
* pH	7.8	7.9	7.9	4.9	6.5	6.7
* Oven Dry Matter, g/kg	781	266	531	543	431	255
* Total Nitrogen (Kjeldahl), g/kg, 100% DM	7.1	47.5	34.9	39.7	56.9	110
Total Phosphorus, mg/kg, 100% DM	899	15800	11600	930	16300	47600
Total Potassium, mg/kg, 100% DM	1750	4820	2010	1620	3180	10400
* Loss on Ignition, % wt/wt, 100% DM					90.9	
*Total Ash %, 100% DM	96.1	52.6	71.4	80.4	9.6	28.7
* Organic Carbon, % m/m, air dried	6.53	13.8	22.9	21.4	31.9	
Total Magnesium, mg/kg, 100% DM	1020	8120	13200	830	1020	1690
Total Lead, mg/kg, 100% DM	<5.00	<5.00	<5.00	<5.00	<5.00	<5.00
Total Nickel, mg/kg, 100% DM	< 1.0	< 1.0	< 1.0	< 1.0	< 1.0	<1.0
Total Zinc, mg/kg, 100% DM	586	17.6	34.8	12.2	51	58.3
Total Cadmium, mg/kg, 100% DM	3.93	<0.25	<0.25	<0.25	0.34	<0.25
Total Chromium, mg/kg, 100% DM	1.71	< 1.00	< 1.00	< 1.00	< 1.00	< 1.00
Total Copper, mg/kg, 100% DM	19	7.3	7.56	1.48	2.4	1.16
Total Mercury, mg/kg, 100% DM	0.1	0.03	0.11	0.01	0.1	0.14
Ammonium-N, mg/kg, 100% DM	1900	8580	3960	1520	5040	9110
*C:N Ratio	9	3	7	5	9	3

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