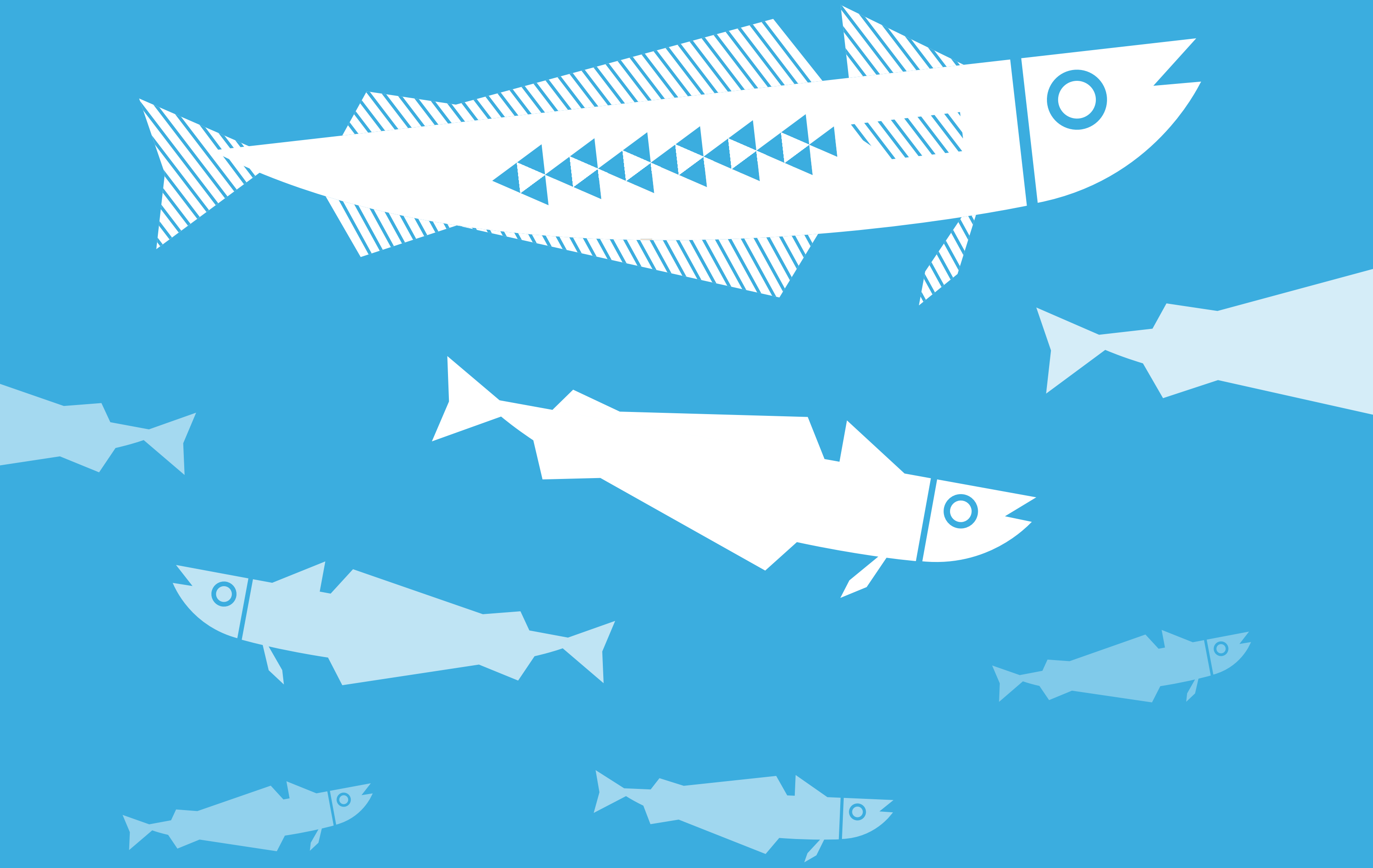
Maximizing Seafood By-Product Utilization: Heads and Viscera Left at Sea

A Case Study on Namibian Hake

March 2023



FRIENDS of OCEAN ACTION

WORLD ECONOMIC FORUM

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Executive summary

Globally, 30% to 35% of seafood caught is lost or wasted in fisheries and aquaculture. Maximizing the utilization of seafood by-products is a key strategy for addressing seafood loss and waste at the post-harvest level. In many cases, increasing the retention and repurposing of by-products would require a significant shift in market demand and value for the associated by-products.

Several key stakeholders in the Namibian fisheries sector have come together to create a forum for pre-competitive collaboration to maximize the utilization of all fish harvested from Marine Stewardship Council (MSC) certified Namibian fisheries while enhancing socioeconomic benefit. This group, the Namibian Ocean Cluster Working Group (NOCWG), has collated pre-competitive data and insights that have enabled the development of this report.

Numerous stakeholder consultations with the Namibian fisheries industry resulted in selecting two by-products representing potential opportunities to maximize economically viable by-product utilization in Namibian hake fisheries, namely heads and internal organs (viscera). This report aims to provide an initial valorization of Namibian hake heads and viscera to understand what the loss of hake heads and viscera to the food system represents in volume, nutrition and market potential.

The information presented in this report was collected using a model to analyze parts of seafood that may have previously been discarded as waste and identify opportunities to market these by-products. In line with the three components of this model – measure, research and markets – industry data were collected, nutritional profiling was conducted and desk-based market research was carried out.

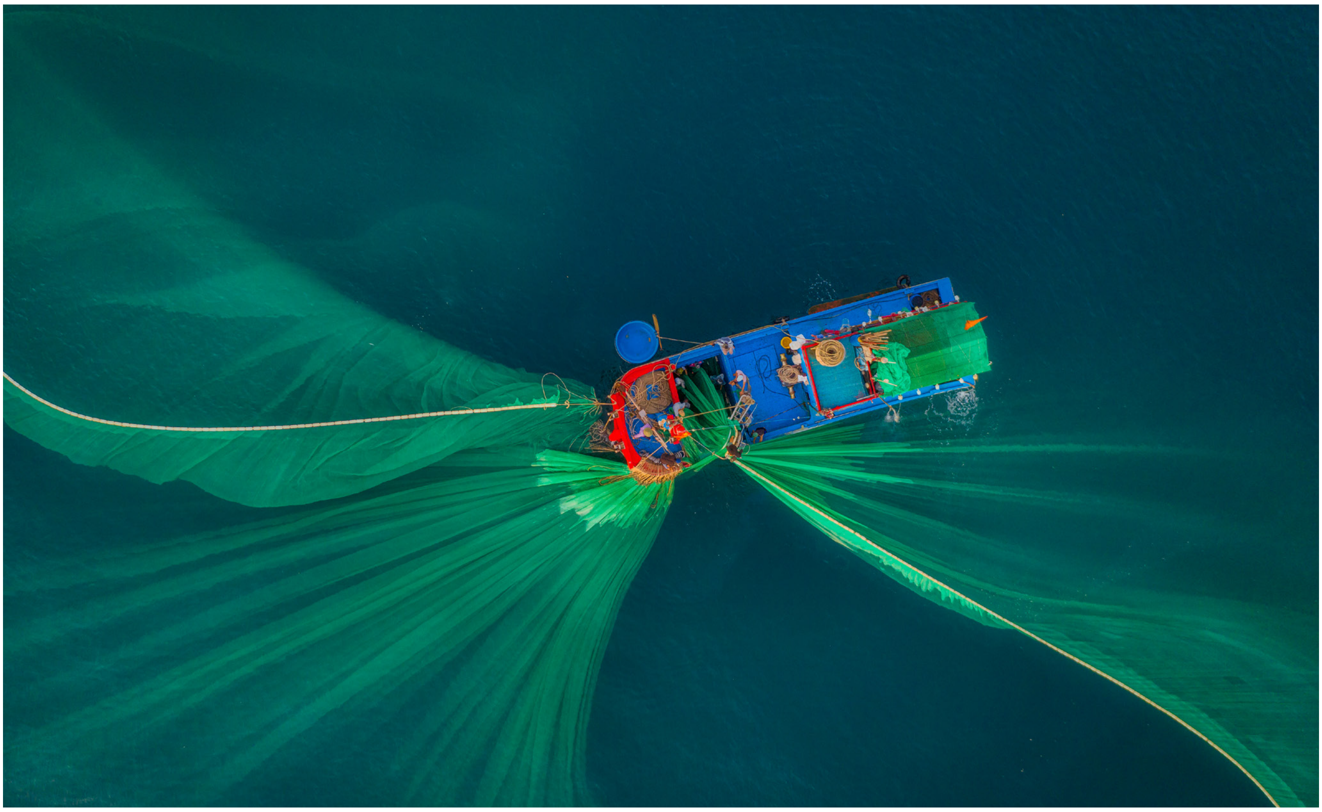
Data analysis was conducted on whole fish weight and the weight of heads, viscera, gonads and livers. This report estimates fish parts left at sea using 154,000 tons as the approximate total for one fishing year (the Namibian hake quote for 2022/23). While the viscera are a relatively small proportion of the fish, the total amount available from the gutting process is estimated at 7,379 tons through the fishing season (November-September). The total amount of livers available was estimated to be 3,474 tons. After liver removal, the remaining viscera represent 3,905 tons. Finally, the total amount of heads left at sea is estimated at 50,843 tons.

The nutritional profiling study investigated by-products of Namibian hake – *Merluccius paradoxus* (deep-water hake) and *Merluccius capensis* (shallow-water hake) – to determine the nutrients that would be available were these by-products retained. Profiling of heads, livers and gonads was undertaken. The study shows that hake livers contain high nutritional content consisting of high levels of omega-3 and omega-6 fats, polyunsaturated fatty acid (PUFA), monounsaturated fat, saturated fat and total energy compared to the heads and gonads. The heads contain significant levels of available protein and calcium. The results indicate that processing some hake parts, particularly livers, can add significant value, converting current waste into economic and environmental gains.

Market research was undertaken to identify opportunities for the heads, livers and gonads, and additional fish parts with potential value. These include hake head soup, canned livers, viscera fertilizer and enzyme extraction for cosmetic and pharmaceutical use. Although established local, regional or global markets were found for all by-products investigated, challenges in capturing these opportunities remain. Firstly, few products have substantial available market data, and thorough research will be necessary to support product development investments. Secondly, several markets currently have low commercial value and are not economically viable. Yet, several medium- to high-value products were identified alongside potential local processing opportunities.

This investigation represents the first global attempt to understand the quantity and nutritional content of by-products left at sea through primary processing on demersal fishing vessels. The report begins to explore what markets could be available to develop by-products alongside the typically targeted parts of the fish. Specific recommendations for the Namibian hake sector are presented; however, the design of this project can be replicated for other fisheries to build a global picture of by-products left at sea. This will lead to a greater understanding of lost nutrition from marine food systems and can ultimately increase the value of each fish harvested as fisheries move towards using the whole fish.

1. Introduction



1.1 Background

Blue food – all edible aquatic organisms from marine and freshwater production systems – play an essential role in ensuring global food and nutrition security while providing livelihood benefits. Blue food provides over 3 billion people with at least 20% of their animal protein.[1] Furthermore, it is increasingly recognized as a unique and extremely diverse provider of essential omega-3 fatty acids and bioavailable micronutrients. Beyond nutrition, about 600 million people depend on fisheries and aquaculture for their livelihoods, 95% of which live in Africa and Asia.

Blue food consumption has doubled over the last 50 years and is forecasted to double again by 2050 as the global population increases.[2] However, 90% of fisheries are fully or over-exploited.[3] These figures highlight the pressing need to increase efficiency from all seafood, whether harvested from the wild or farmed.

Globally, 30% to 35% of seafood caught is lost or wasted in fisheries and aquaculture.[4] Food loss and waste is a decrease in the quantity and quality of food, which can occur at different stages of the value chain.[5] The High Level Panel for a Sustainable Ocean Economy, an initiative consisting of 17 world leaders building momentum for a sustainable ocean economy, identified reducing seafood loss and waste as a critical transformative objective for a sustainable ocean economy, marking an important step in international recognition of the urgency to address seafood loss and waste.[6]

According to the FAO, maximizing the utilization of harvested seafood by-products is a key strategy for addressing seafood loss and waste at the post-harvest level.[7] The by-products are the parts of the fish left after attaining the desired products for human consumption. Growth in fisheries and aquaculture production has resulted in increasing quantities of seafood by-products, usually composed of heads, internal organs (viscera), skin, bones and scales. Efficient management and utilization of by-products – increasingly called co-products – and their conversion into value-added products can lead to better resource use and profit maximization, resulting in employment creation and economic growth.[8] Equally, recovering valuable content such as fish oil from fish waste may diminish industrial fishing pressure on fish stocks.[9]

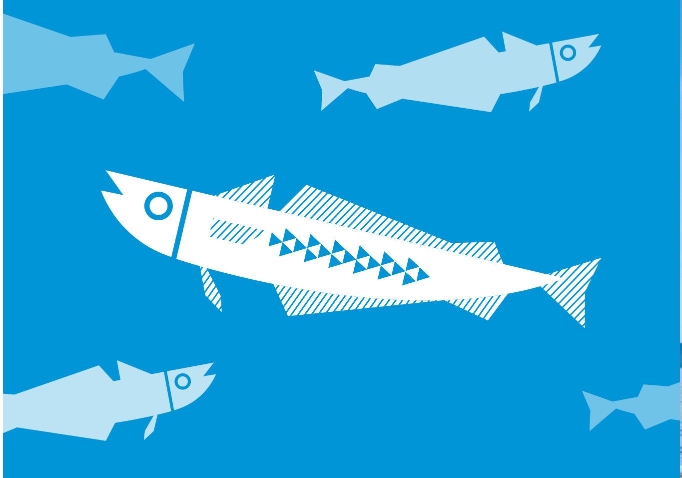
1. Introduction

Designing effective strategies for maximizing by-product utilization requires understanding why it takes place.[10] For example, numerous demersal fish, which live on or close to the bottom of lakes or seas, will undergo some form of processing at sea, often involving discarding by-products to ensure a higher quality prime product.[11] Reasons for bringing in headed and gutted product range from quality and hygiene factors to market specifications and economies of scale associated with bringing higher value fish parts ashore. Therefore, maximizing the retaining and repurposing of by-products would require a significant shift in market demand and value.

There are many uses for seafood by-products, ranging in value economically, nutritionally and in their application. Some are destined for indirect human consumption (e.g. fish meal in animal feed), while others are used directly for human consumption (e.g. heads). There are also increasingly high-value markets for by-products, such as biotechnological (e.g. wound dressings) and pharmaceutical applications, which offer a significant and sustainable source of high-value bio-compounds (e.g. collagen).[12] Some final products will require substantial investment and technology; however, other "low-hanging fruit" do not require sophisticated investment but can still obtain reasonable returns.

Globally, little information is available on the total volumes of seafood by-products going to waste. However, researchers in Namibia have made a start to understanding the characteristics of seafood by-products. The commercial fishing industry in Namibia is dominated by hake, horse mackerel and monkfish. Peer-reviewed research in Namibia explores the characteristics of seafood by-products and the challenges and opportunities associated with using them.[13] This report builds on this research, focusing on hake fisheries: the second fisheries in Africa to receive Marine Stewardship Council (MSC) certification.

The challenge faced by global fishing industries is understanding the type of by-products currently going to waste, quantifying the amount of these by-products available in terms of volume and nutrition, and exploring economically viable alternative products that can provide socioeconomic benefit. This exploration is believed to be the first that seeks to understand these three parameters in tandem, and presents a model applicable to all fisheries to measure the quantity of by-products left at sea.



30-35% of seafood caught is lost or wasted. Addressing this could boost resource use, profit and sustainability.

1. Introduction

1.2 Objective

The Namibian Ocean Cluster Working Group (NOCWG), convened by the World Economic Forum, is creating an aligned approach to maximizing by-product utilization, thereby capturing more nutrition and reducing seafood loss. The project seeks to create replicable models that seafood businesses worldwide can use to enable the maximum utilization of by-products in economically viable and market-appropriate ways. By combining pre-competitive data and agreeing to share the results of this preliminary investigation, the NOCWG has enabled the development of this report.

Consultation with the Namibian fishing industry informed the focus of this investigation on two potential opportunities, heads and viscera. There was a broadly shared understanding that fish heads are a widely accepted part of the food portfolio in many countries throughout Africa and Asia and that parts of the viscera, especially the liver, have high nutritional content.

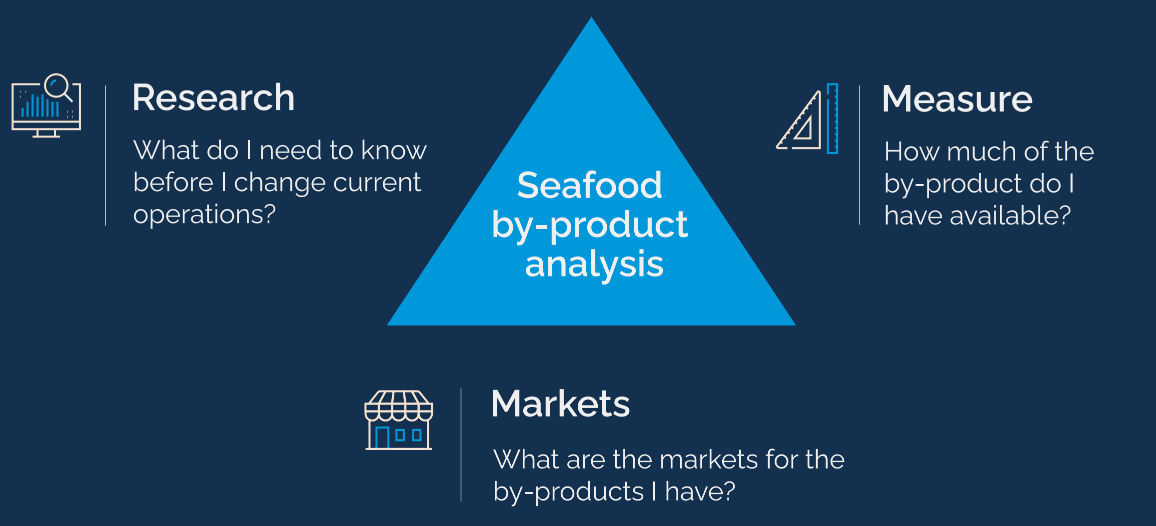
Though global research shows that 37% of hake heads and viscera are left at sea,[14] it is unclear what this means in real terms. Therefore, the objective of this report is to provide an initial valorization of Namibian hake heads and viscera, to understand what the loss of hake heads and viscera represents in terms of volume, nutrition and market potential, and what it would take to land all, or some, of these by-products for repurposing. This will be done by quantifying the loss of heads and viscera left at sea in the Namibian hake sector, conducting nutritional profiling of heads and viscera, and delineating potential markets.

1.3 Approach

The data presented in this report were collected in three ways, in alignment with the model shown in Figure 1. This model illustrates how seafood producers and processors can begin to analyze the fish parts often discarded as waste and identify opportunities to market them. In line with the three components of the model – measure, research and markets – industry data were collected, nutritional profiling was conducted and desk-based market research was carried out.

The results presented here should not be viewed as scientifically conclusive. Instead, they should be considered as a first step in exploring opportunities to reduce seafood loss in Namibian fisheries.

Fig 1. A model for seafood by-product analysis



Source: Friends of Ocean Action, *World Economic Forum, Maximizing seafood by-product utilization towards eliminating waste*, 2022

1. Introduction

1.3.1 Measure: industry data

The first part of the analysis is to understand the total weight of by-products available along with seasonal or another temporal variability. The quantity may influence whether it can be provided directly to a market or needs to be combined with other sources for supply to be sufficient. Industry representatives and other stakeholders provided data that estimated the total quantity of by-products. To assess gonads containing eggs, also known as roe, only female fish were sampled.

1.3.2 Research: nutritional profiling

The second analytical step is to close knowledge gaps on the nutritional opportunities presented by these by-products. Dr. Victoria Erasmus conducted a nutritional profiling study of female hake samples provided by several NOCWG members. Her team conducted nutritional profiling on the heads, livers and gonads. Discussion with industry stakeholders and Dr. Erasmus steered the selection of these two parts of the viscera, as these were deemed to have the most likely potential for socioeconomically viable repurposing. The selection of nutritional components was informed by advice from Dr. Erasmus and other expert scientists.

1.3.3 Markets: desk-based market research

The third part of the analysis involves exploring potential markets. A combination of desk-based research of publicly available information and consultations with the NOCWG were undertaken to investigate potential local, regional and global markets for hake by-products. This information will enable stakeholders to identify and prioritize suitable product ventures from the options presented.

2. Quantifying seafood by-products left at sea

2.1 Global estimation of seafood by-products left at sea

Globally, 1.5 to 25 million tons of by-products are left at sea annually.[15] This large 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 estimates of by-products left at sea for four fish types are shown in Table 1.

There is a lack of publicly available data that could help determine the true volume of seafood by-products left at sea, emphasizing the need to understand actual volumes.

2.2 Why by-products are left at sea in Namibia

In Namibia, most hake catch is headed, eviscerated on vessels and left at sea. An estimated 30% of the catch is therefore unavailable to any on-land facility for further processing. Regarding the heads, the value of markets is perceived as too low to cover the cost of handling, storage, landing and onward distribution. In terms of viscera, gutting the fish at sea helps maintain a higher quality of the prioritized product for onshore processing. Furthermore, handling the viscera and preventing its deterioration has been considered too difficult to be viable on traditional vessels. Some of the newer vessels have viscera storage tanks, but the ports have limited facilities for bringing them ashore. It should be noted that a small number of heads are landed for local consumption, and viscera, where landed or available, is sold to local fish meal plants.

To date, fishing vessels have mostly been designed to bring ashore products for human consumption that already have proven markets and make a commercial profit. This means the by-products not currently considered commercially viable are left at sea to maximize space for products that have proven viable markets.

There are three main types of commercial fishing vessels in the Namibian hake industry, wet fish trawlers, factory freezer vessels and longline vessels. By-product use and handling varies with each vessel type. Each type of vessel guts at sea, and all but the longline vessels – due to their catching method – head fish at sea.

2.3 Quantifying by-products left at sea in Namibia

2.3.1 Defining the by-products

In Namibia, a small quantity of heads is processed at sea, as the cheeks and tongues are extracted and landed. Additionally, a small proportion of gonads are extracted from the viscera if they are substantial in size. Though small in volume, these are high-value products, mainly for European markets, and require intensive processing at sea.

Table 1: Percentage yields of by-product categories for main "types" of fish, based on live weight

Fish type	By-product categories and percentage yields		
	Guts (%)	Heads 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

Source: RS Standards, *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, 2022*

2. Quantifying seafood by-products left at sea

Where fillets are produced at sea on factory freezer trawlers, the fish frames (bones), skin and some trimmings, including tails, are additional by-products left at sea.

Once in onshore processing factories, headed and gutted hakes are further processed into fillets, loins and other value-added human consumption products for retail and international foodservice markets. In some cases, molded hake products are made from meat trimmings. Onshore, the emphasis is to maximize yield from the headed and gutted product. By-products captured, such as fish frames, skins, scales, trimmings and tails, are mostly sent to two fish meal processors, Exigrade Feeds and SeaNam Fishmeal Processors.

2.3.2 Quantities left at sea

Breakdown of heads and viscera as by-products

Based on a spot sample of 98 whole hake taken from a commercial vessel fishing trip in December 2022, data analysis was conducted on whole fish weight and weight of heads, viscera, gonads and livers. It is key to note that these samples were caught at one point in time in only two geographical areas, so they do not represent the full range of hake sizes during a fishing year.

Figure 2 demonstrates that the heads constitute the greatest percentage of by-products left at sea. Comparatively, the viscera represent a small proportion of the whole fish weight. Looking specifically at the viscera, the livers constitute almost 50% of the viscera weight. The gonads are small, which is likely due to seasonal timing.

Total of heads and viscera available

The calculations below are based on the breakdown of fish parts data shown in Figure 2.

Figure 2. Fish parts as a percentage of whole fish weight

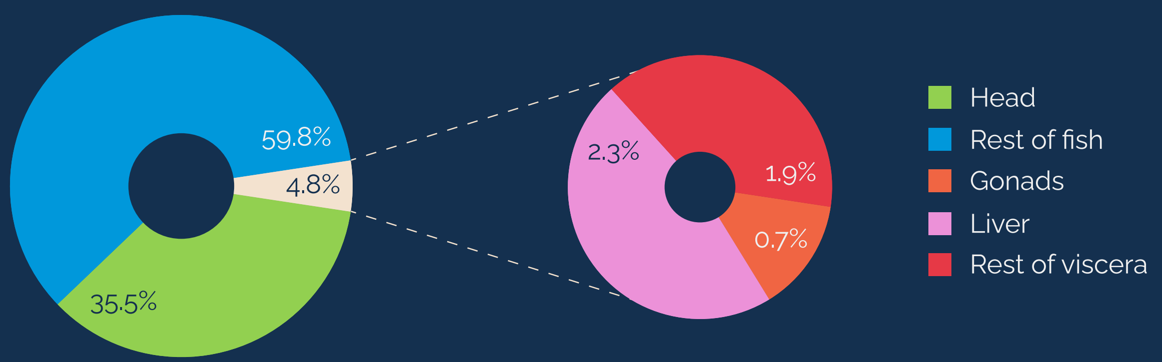


Table 2: Approximate tonnage of hake by-product as a proportion of total tonnage quota allocation

Fish parts	Proportion of processes resulting in by-product left at sea	Percentage of whole fish	Total approximate tons from 154,000 tons quota allocation
Viscera	100%	4.8%	7.379
Heads	93%	35.5%	50.777
Liver	100%	2.3%	3.474

2. Quantifying seafood by-products left at sea

Table 2 includes three assumptions. First, 100% of all hake caught is eviscerated, as all vessels gut hake onboard. Second, 93% of all hake is headed because 7% is longline caught. Third, the full annual quota allocation is caught. Under these assumptions and the proportions previously described, the heading and gutting processing at sea results in approximately 7,379 tons of viscera, 3,474 tons of livers and 50,843 tons of heads.

What else is in the viscera?

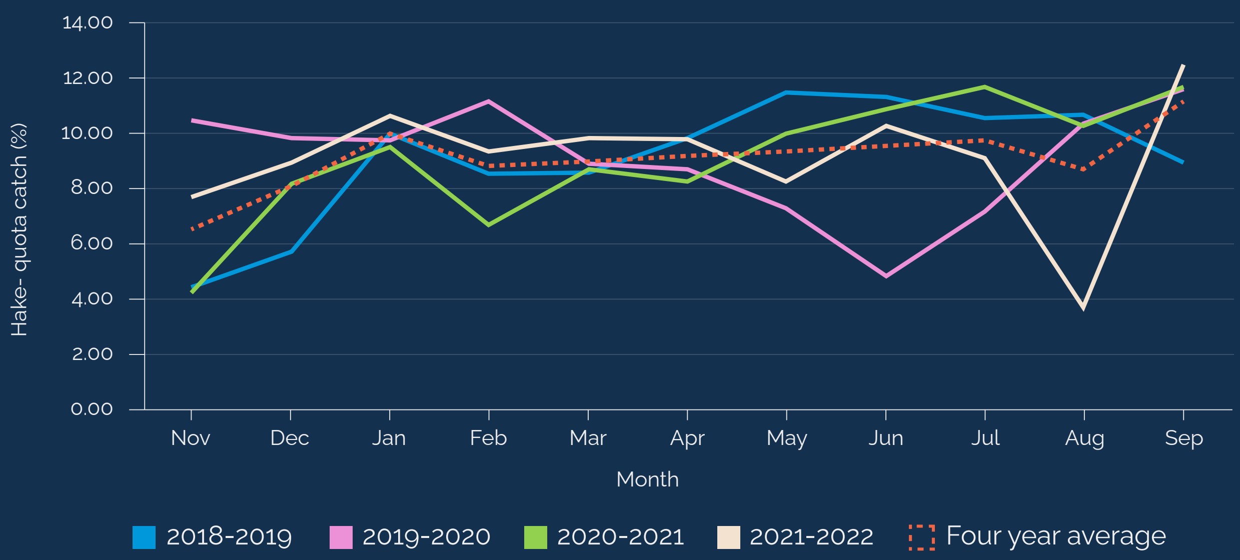
In addition to the liver and gonads, the viscera includes the heart, kidney, stomach, intestines, gall bladder and spleen. The swim bladder is also present, although this can be attached to the backbone, so may not be removed in the evisceration process. In February 2023, a sample of 11 whole hake was taken from a commercial fishing trip to analyze and identify the contents of the viscera. The organs were weighed to assess their comparative weights as a percentage of the whole viscera, presented in Table 3. This indicates that the two largest organs are the intestines and stomach, accounting for 20% and 26%, respectively.

Table 3: Fish viscera breakdown as a percentage of whole fish and viscera

Fish part	Percentage of whole fish	Percentage of viscera
Viscera	5.1%	100.0%
Gonads	0.4%	7.9%
Spleen	0.0%	1.0%
Heart	0.1%	2.5%
Intestines	1.0%	19.9%
Liver	1.9%	38.3%
Stomach	1.3%	25.9%
Rest of viscera	0.2%	4.6%

2. Quantifying seafood by-products left at sea

Fig 3. Monthly catch percentages of total quota by a large Namibian hake trawling company over four years



Changes in the quantity of hake caught over the fishing year

Figure 3 shows the landings of a large hake trawling company. This data covers the four years starting November 2018 through to the end of September 2022. The month of October is closed to fishing for hake to promote hake reproduction during the spawning season.

Historically, hake catches reduced during winter, and vessel captains emphasized conserving vessel equipment when the seas were rough. More recently, companies have acquired larger vessels, creating greater flexibility and catching efficiency year-round.

The table shows that catches are relatively consistent over the whole year. Many vessels undergo annual servicing and repairs in October, so not all are operational in November at the start of the fishing year. In September, catches are higher in an effort to catch the whole quota before the end of the quota year-end deadline.

Seasonality of by-products

The main seasonal by-product is gonads. These become larger as the fish move into the spawning season in the second half of the year. The spawning months are July through October and can vary in intensity during these months based on annual environmental conditions.

2.4 Storage and handling capacity

One key challenge to the increased utilization of seafood by-products is storage and handling capacity both at sea onboard the vessels and when landed.

2.4.1 At sea

Where vessels are nearing the end of a fishing trip and will not use all their bins of ice for headed and gutted fish, there is an opportunity to use the remaining ice and available space to bring by-products to shore. Where by-products from within the viscera are recovered, due to the high level of enzymes in the viscera, on-vessel processing plans will need to be developed.

Research is needed to identify novel methods of extending the period for collecting fresh gonads during a fishing trip. Due to fast degradation, they are only gathered during the last two days of catch on wet fish trawlers, where they are stored on ice. It is noted that in Iceland, the roe is frozen or preserved

using salt.[16] For livers, which are more difficult to handle than gonads, insight is required in handling techniques and establishing the most efficient way to bring them ashore.

Heads are bulky and would compete for space with prime quality products if they were to be landed. For this to be justified financially, a market that increases the value of hake heads considerably must be identified. Subject to the available equipment, it is also possible to mince heads at sea and then crush them to compact them onboard the vessel for more efficient storage. This crushed product could then be brought ashore to include in fish meal.

Several other parts of the fish are processed at sea, each presenting a different practical challenge for bringing by-products ashore. For example, when processing fillets aboard factory freezer vessels, if the backbone is removed, approximately 30% of the meat on the bone may be lost, depending on the removal technique. In addition, due to customer demand, hake factory freezer trawlers are focusing more and more on skinless fillets, which means the skins are also left at sea.

Finally, the fish parts must be separated onboard to obtain specific organs. This will likely require additional tools, skill training and human resource.

2.4.2 Processing and handling

Some vessels have tanks that hold viscera to bring to shore, which is currently sent to fish meal plants. Logistics for pumping the waste ashore is a key issue, and investing in a truck with a pump and a tank is necessary to offload the viscera efficiently. A financial analysis is required to show the economic viability of these types of activities.

Regarding by-products post-landing, the Namibian fishing industry, from a processing capacity perspective, is not geared to handle large quantities. Some companies, particularly those longlining for hake, sell hake heads locally in Namibia, where the fish is not exported. This occurs either through their own fish distribution networks or, in the case of the Namibia Fish Consumption Trust in Luderitz, through their fish shop. Some wet fish trawl companies are landing heads and selling them through their distribution networks to different parts of Namibia, particularly the north, where most of the human population is. This activity is relatively experimental, and the viable price point for the heads is still being defined.

Currently, most fish processing factories are fully or nearly fully utilized. Hangana Seafood of Walvis Bay has built a new fish factory, leaving the previous facility unused. This could be used for by-product processing. There are currently no logistical means to pump the waste ashore, so the infrastructure requires investment; however, a chiller is present. Based on financial viability, Seawork Seafood Processors have some spare onshore processing capacity, which could be adapted if needed.

If by-products are shown to be profitable, they can be maintained to either follow normal processing channels or treated using newly developed on-land facilities. Because of potential high bacterial counts in the viscera, a new processing management plan is necessary, supported by external expert advice.

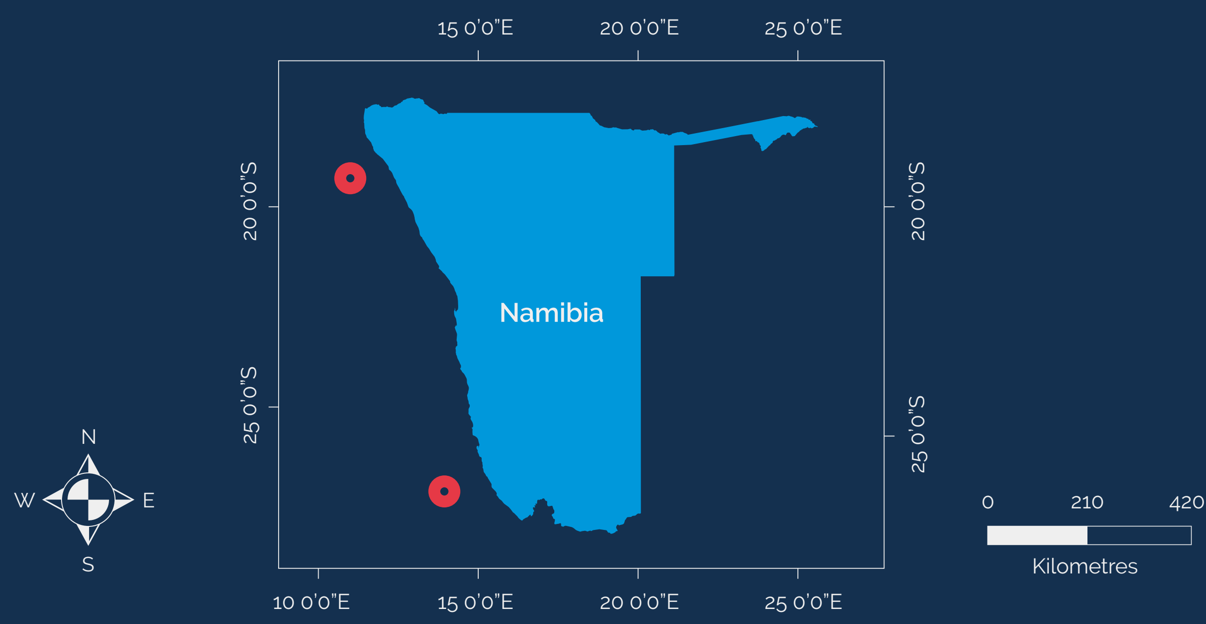
2.4.3 Storage

To explore where there is capacity to store by-products if they are to be landed, pre-competitive collaboration between industry stakeholders is important. For example, Hangana Seafood, located in Walvis Bay, currently has available cold storage capacity. In the future, leasing the property to other industry players is possible. Other fishing companies also have cold storage facilities but are generally close to using them to full capacity. Additionally, Walvis Bay has large commercial cold storage facilities, but the rates for holding the product would surpass the commercial value of any by-products.

The Namibia Fish Consumption Promotion Trust has cold storage capacity and distribution trucks to take fish parts to their fish shops, which are dispersed regionally throughout Namibia.

3. Nutritional content of hake heads and viscera

Fig 4. Geographical positions where hake samples were collected off Namibia during December 2022.



Building on previous research by Erasmus et al., this nutritional profiling study investigated by-products of Namibian hake (deep-water hake, *Merluccius paradoxus,* and shallow-water hake, *Merluccius capensis*), to determine the amount of nutrients that would be available if these by-products were to be retained and repurposed.[17] The study aims to provide the profiling of nutritional content of three potentially high-value Namibian hake by-products: livers, heads and gonads.

3.1 Methodology

This project used hake samples collected at latitudes 18° and 27°S off the Namibian coast, shown in Figure 4.

A total of 58 female fish (33 *M. capensis* and 25 *M. paradoxus*) were considered. They ranged in size from 49cm to 66cm and were caught on 16 and 17 December 2022 at 218m and 295m water depths. In the laboratory, the samples were aggregated into *M. capensis* and *M. paradoxus*. For nutritional profiling, only ten fish were processed (six *M. paradoxus* and four *M. capensis*). All gonad samples from both species were combined to meet the minimum volume for analysis. Thirty samples (ten heads, ten livers and ten gonads) were transported to a laboratory in South Africa for nutritional profiling and then sub-sampled to an outsourcing laboratory for vitamin analyses.

Samples were analyzed for the following:

- Omega-3 long-chain polyunsaturated fatty acids (LC-PUFA): Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)
- Fatty acid profiles (including saturated fat, monounsaturated fat and polyunsaturated fat)
- Bioavailable protein (using the international method of estimating protein content by quantifying nitrogen content. The nitrogen to protein conversion factor for meat and fish is 6.25.)
- Vitamins B12 and D3
- Calcium
- Iodine
- Dietary fibre
- Carbohydrates and energy values (calculated based on ash and moisture).

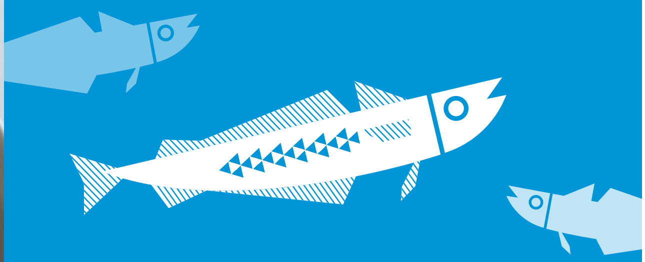
3.2 Nutritional components

Table 4: Average nutritional profiling of hake by-products

Nutrient	Unit	M. paradoxus heads	M. capensis heads	M. paradoxus livers	M. capensis livers	Combined gonads
Proteins	g/100g	16.18	15.05	8.59	8.1	15.5
Total fat	g/100g	0.8	0.79	42.7	44.9	2.46
Saturated fat	g/100g	0.25	0.28	12.2	13.9	0.8
Monounsaturated	g/100g	0.28	0.32	21.8	20.7	1
Polyunsaturated fat	g/100g	0.26	0.22	8.7	10.3	0.7
Omega-3 fat	mg/100g	222.6	184.25	7,728	9,134	608
Omega-6 fat	mg/100g	<100	<100	930	1135	<100
Dietary fibre	g/100g	<1.0	<1.0	<1.0	<1.0	<1.0
Carbohydrate	g/100g	1.4	<1.0	5.2	3.4	<1.0
Total energy	calories/100g	69.5	69	434	444	86
Calcium	mg/kg	16,050.5	24,667	49	117	98
Iodine	µg*/kg	232.5	204.25	2,342	1,494	165
Vitamin D_3	µg/100g	4.4	3.5	19.7	7.5	<1
Vitamin B_{12}	µg/100g	0.48	0.55	21.7	32.4	15

< means results are lower than the minimum quantifiable limit.

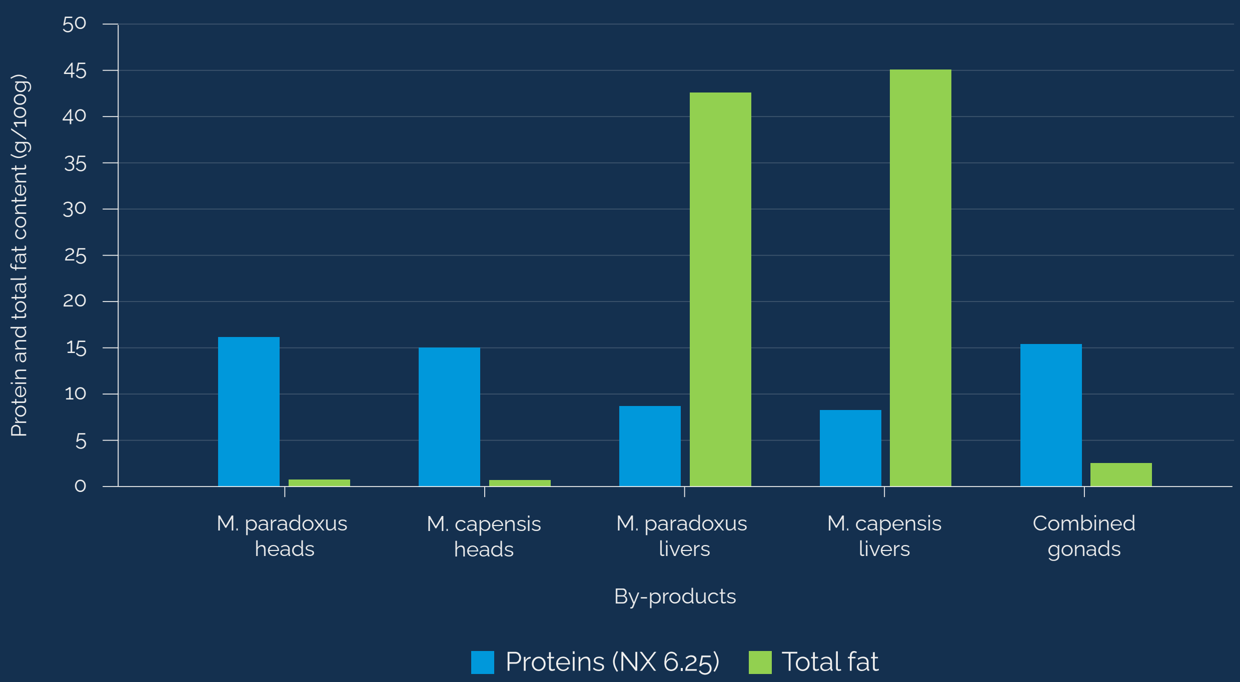
*micrograms



Investigating hake by-products reveals untapped nutritional potential, rich in omega-3 fatty acids, bioavailable protein, vitamins, calcium and iodine – a sustainable resource.

3. Nutritional content of hake heads and viscera

Fig 5. Protein and total fat in Namibian hake by-products



Bioavailable protein

Bioavailable protein content was highest (16.18 g/100g) in the *M. paradoxus* heads and lowest in the livers of the two hake species (see Figure 4).

Total fat

Total fat was highest in the liver samples. Total fat was poorest in the heads of both species and only slightly higher for the gonads (see Figure 4).

Fatty acid profiles

The human body cannot synthesize certain fatty acids; hence, these essential fatty acids must be consumed in the diet.[18]

Omega fatty acids

Omega-3 (n-3) fatty acids are polyunsaturated fatty acids. Omega-3 fatty acids can be obtained mainly from two dietary sources: marine and plant oils. EPA and DHA are the primary marine-derived omega-3 fatty acids. Marine fishes are high in omega-3 fatty acids.[19] The European Food Safety Agency (EFSA) has made certain recommendations to intake at least 250mg/day of a combined dose of EPA and DHA for adults to protect them against cardiovascular diseases.[20]

Analyses of this component show that the liver is a good source of omega-3, with 7,728mg/100g and 9,134mg/100g in *M. paradoxus* and *M. capensis*, respectively (see Figure 6). This indicates that a 10g portion of hake liver would provide approximately 0.84g of omega-3. By comparison, a single lean fish meal (e.g. one serving of cod) could provide about 0.2 to 0.3g of these fatty acids, while a single oily fish meal (e.g. one serving of salmon or mackerel) could provide 1.5g to 3g.[21]

3. Nutritional content of hake heads and viscera

Omega-6 fat was highest in the livers of *M. capensis* (1,135 mg/100g). Omega-6 fat was below detection rate in the fish heads and gonads (see Figure 6).

Saturated and monounsaturated fat

A comparison of the saturated and monounsaturated fat content in the three hake by-products shows that the livers of both species had the highest contents (see Figure 7).

Fig 6. Omega-3 and omega-6 in Namibian hake by-products

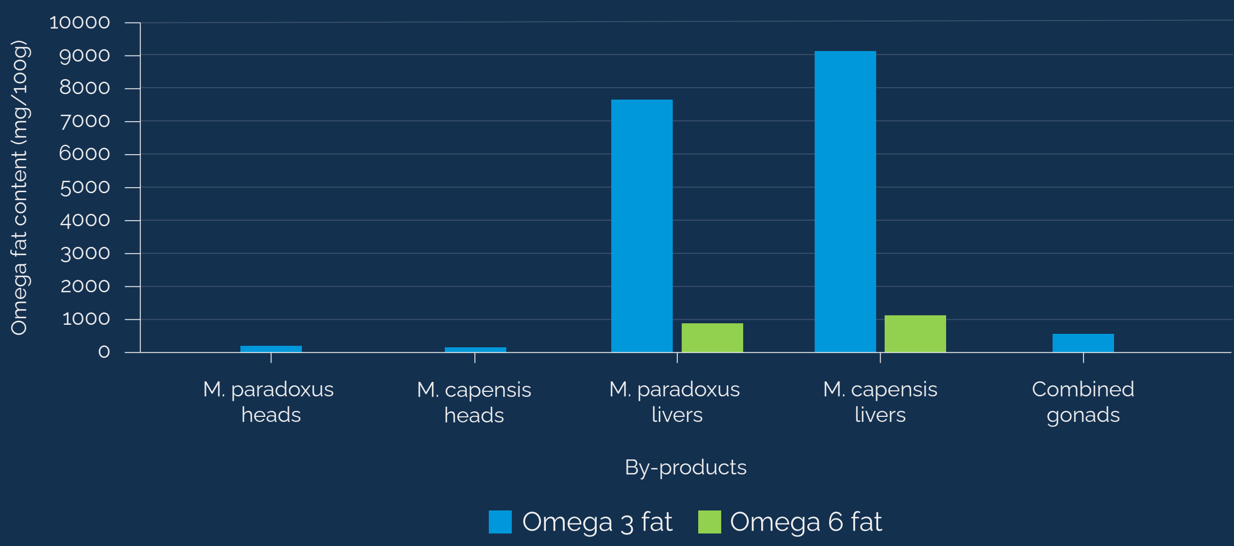
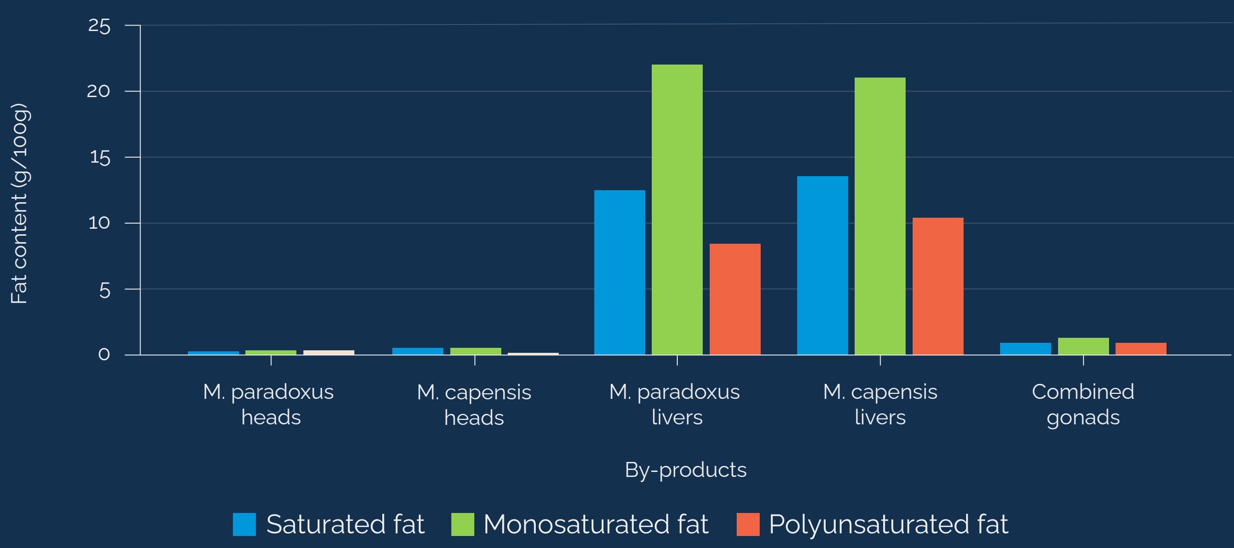


Fig 7. Saturated, monounsaturated and polyunsaturated fat in Namibian hake by-products



3. Nutritional content of hake heads and viscera

Polyunsaturated fatty acids

Seafood is known to be the main source of polyunsaturated fatty acids (PUFA); therefore, humans obtain most of their EPA and DHA by consuming fish, aquatic invertebrates, and algae.[22] Among the fatty acids, highly unsaturated n-3 fatty acids (n-3 HUFA) or long--chain n-3 polyunsaturated fatty acids (LC n-3 PUFA), particularly EPA and DHA, affect human health, early development and the prevention of some diseases.[23]

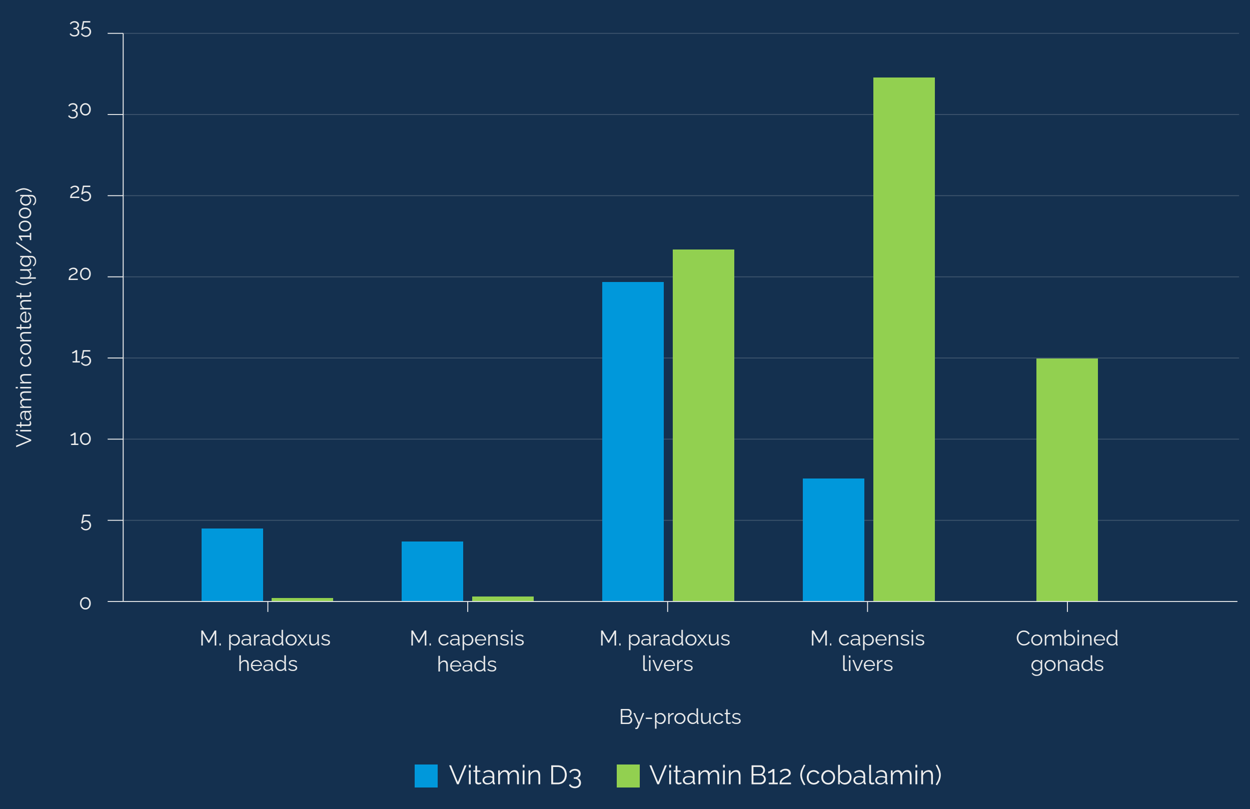
Results show that the livers had the highest PUFA content while the heads had the least (see Figure 7).

Vitamin B12 and vitamin D3

Vitamin B12 (cobalamin) is a rare nutrient, necessary for the normal functioning of the brain and nervous system, cognitive functioning (ability to think), formation of red blood cells and anaemia prevention, helping create and regulate DNA, among other benefits.[24] The recommended daily allowance for vitamin B12 differs with age. For example, adults aged 19 and over require a daily intake of 2.4 µg/day.

Comparisons of vitamin B12 in the three by-products indicate that the content was highest in the livers (21.7-32.4 µg/100g), followed by the gonads and the heads. Vitamin D3 was highest (19.7 µg/100g) in the *M. paradoxus* livers, more than twice that of the *M. capensis* livers (see Figure 8).

Fig 8. Vitamin D3 and vitamin B12 content in Namibian hake by-products.



3. Nutritional content of hake heads and viscera

Calcium

The heads had the highest calcium content scoring around 16,000 mg/kg (see Figure 9). This is likely due to the presence of bones in the heads. Appropriate calcium intake has shown many health benefits, including a reduction of hypertensive disorders of pregnancy and lower blood pressure, particularly among young people.[25]

Iodine

On average, the livers had more iodine content than heads and gonads. In particular, the livers for *M. paradoxus* had the highest iodine content (2,342.0µg/kg) (see Figure 10). Iodine is a mineral nutrient that the thyroid gland needs to produce hormones, which regulate many bodily functions, including growth and development.[26] Iodine is not produced by the human body and must be obtained through diet; thus, it is an essential mineral. Natural sources of dietary iodine include marine fish, iodized salt, seaweed and some dairy products.[27,28]

Fig 9. Calcium content in three Namibian hake by-products: heads, livers and gonads

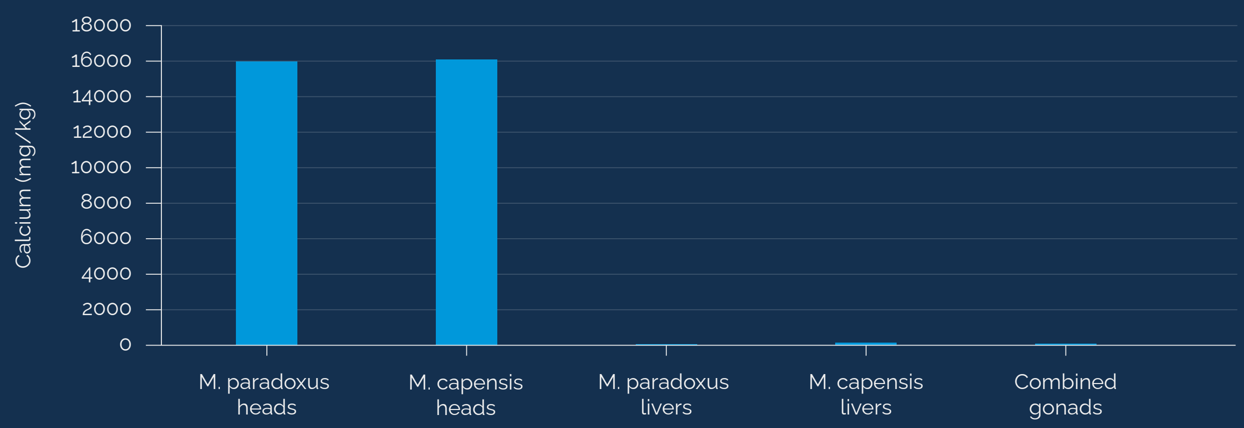
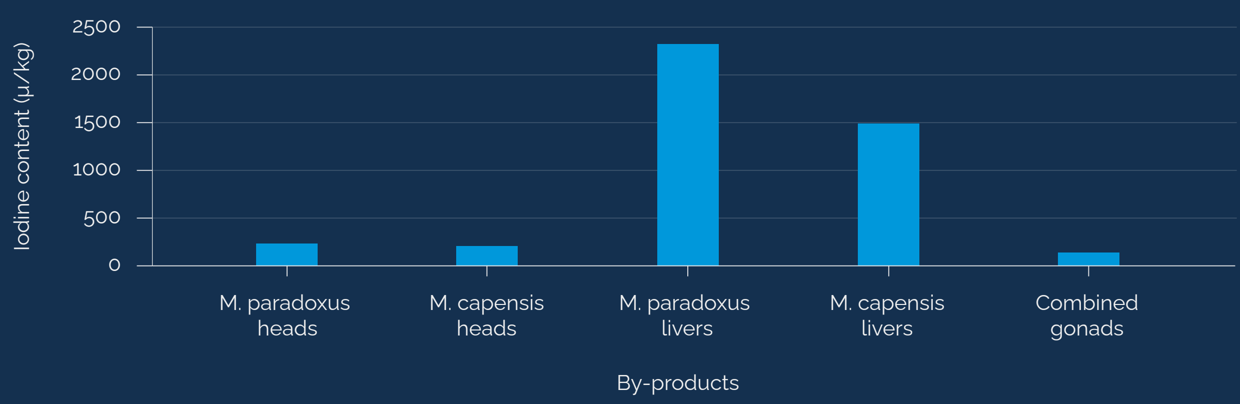


Fig 10. Iodine content in Namibian hake by-products



Carbohydrate

Carbohydrate was low in all components (all below 10g/100g). The *M. paradoxus* liver reported the highest carbohydrate content at 5.2g/100g (see Table 4).

Dietary fibre

Dietary fibre was low (all <1.0 g/100g) in all hake by-products analyzed (see Table 4), implying that all three by-products are poor sources of dietary fibre.

Total energy

Total calories, although a non-nutrient component of food, provides a measure of how much energy you get from a serving of this food.[29] Total energy reported in calories/100g was highest in the liver of both species (see Table 4).

3.3 Implications of nutritional value estimates

This profiling was undertaken to help understand the amount of nutrition left, and therefore lost, at sea and how the nutritional profile might enhance opportunities for new primary products. The results show that the processing of by-products has the potential to produce value-added, nutritional products and convert the current waste into economic and environmental gains.

Among the three by-products analyzed, the livers were the most nutritional in terms of omega-3 fat, omega-6 fat, saturated fat, polyunsaturated fat, monounsaturated fat, vitamin B12 and vitamin D3. Furthermore, the liver had the highest total energy and carbohydrate content. The liver is rich in protein, which is vital in turning food into energy. If retained, hake livers could be a large source of nutrition for human consumption. It should also be noted that many parasites were observed on the livers, which calls for caution when selecting livers for repurposing.

Gonads are considered a highly nutritional food. Gonads were more nutritional than the fish heads (especially in total fat, omega-3 fat and vitamin B12) and thus could be a good product opportunity in the market. However, it should be noted that the gonad opportunity would probably be seasonal, as this project demonstrated that December might not be the best month to collect gonads in large quantities as food for human consumption. Larger gonads will likely be encountered between July and October: the documented spawning peak for shallow-water hake in Namibia.[30]

Although the fish heads had the most weight, they were the least nutritious in omega-3 and fats compared to the livers and gonads. However, because the calcium and bioavailable protein content were highest in the heads, they remain an important source of nutrition. Because of this and the significant mass of the heads, they should be considered a high-potential by-product. Different nutrition types suggest different product offerings are possible from each fish part.

4. Markets

This section outlines the potential markets for four hake by-products: heads, livers, gonads, and the other viscera. The information provided uses publicly available data from market and trend analyses, and as such, some by-product markets have considerably less information than others. Additional information on Namibian processors is provided as these presents potential new partnership opportunities.

4.1 By-product: hake heads

4.1.1 Local market

Various types of fish heads are currently sold in the Namibian market, including heads from angel fish, snoek and hake. All are sold in frozen form by fishing companies. In the north of Namibia, some customers then dry the heads, as refrigeration is not always available. Customers also produce fish soup from the heads. In addition, fish heads can be sold for bait. However, market prices and freight costs currently make most local markets uneconomical.

At present, a small number of hake heads are landed in Namibia. They are typically bagged and sold locally very quickly. These originate from longline caught hake, where the hake is landed head-on or is brought in by wet fish trawlers when space onboard allows. They are not landed in higher numbers because the Namibia sales price is currently too low to be economically viable. There is demand for the product, but the sales price must increase for companies to land more heads.

Value-added products

Although heads are typically sold unprocessed, product development opportunities may add significant value and increase their economic viability. One example is to explore product development with the local food processing company African Deli.

Case sudy 1: Namibia Fish Consumption Promotion Trust

Namibia Fish Consumption Promotion Trust (NFCPT) is a government agency headquartered in Walvis Bay. The trust's primary objectives are threefold:

- To familiarize Namibians with their fish and nutrition
- To improve the accessibility of fish
- To improve the affordability of fish

These objectives are being achieved through the promotion, processing and distribution of fish.

The trust owns and operates six trucks servicing 18 fish shops nationwide. It also has freezer storage facilities in Walvis Bay. Currently, most fish sold through the fish shops is whole horse mackerel. Hake heads are popular when available, and the NFCPT would welcome more heads to sell, as they are both nutritious and affordable.

NAMIBIA FISH CONSUMPTION PROMOTION TRUST

Case sudy 2: African Deli

Food products company African Deli, located in Walvis Bay, create a range of vacuum-packed ready-to-cook meal items distributed in Namibia and South Africa. The range currently consists of several animal proteins within a sauce, including chicken livers and vegetables. One of the benefits of vacuum-packed foods is their elongated ambient shelf life.

There are currently no fish meal items in the African Deli range. The company is exploring soup recipes, of which fish heads may be a viable ingredient. The established specialist processing plant is local to the seafood companies. The optimum location combined with proven, well-practiced new product development methods, including market testing and distribution channels, make this a promising opportunity to explore further. It takes around one year from the start date to a shelf-ready product and costs in the region of NAD 1,000,000 (Namibian dollars).

AfricanDeli
COMMITTED TO QUALITY PREPARED GOODNESS

4.1.2 Regional market

Fish heads are welcomed and make a nutritious addition to African regional food portfolios. Reliable publicly available data are difficult to establish, given that heads sales are often amalgamated with other parts, for example, swim bladders and tails. However, the general trend suggests that the demand for heads across Africa is rising.

Norway is exporting a large number of fish heads to Nigeria. In 2018, 6,100 tons of dried fish heads, worth $16 million, were exported from Norway to Nigeria.[31] Some data suggest that Nigeria is the African country with the largest volume of fish parts consumption, accounting for 65% of total volume.[32] However, there is no consistent reporting of imports and exports across all countries.

4.1.3 Global market

Many countries worldwide use fish heads as a part of their everyday diets, whereas some cultures consider them a delicacy and give the fish head to the most senior person at the table. Neither details on species nor trade appear to be well documented but may be available by commissioning specialist research.

Heat from a fish meal plant could potentially be used to dry heads, improving their storage capability in markets where cold storage is less available and maintaining their quality when exported.

4.1.4 Secondary products from heads

Fish cheeks are celebrated by consumers throughout the world. Typically, these come from monkfish, halibut or cod. Hake cheeks are welcomed in Spanish markets, known as “cococha”. They are generally purchased chilled, frozen or tinned in olive oil. There is a small export market of hake cococha from Namibia. Similar to fish cheeks, a small but relatively high-value market exists for fish tongues; however, given the product’s small size, it involves intense processing.

4.2 By-product: hake livers

4.2.1 Local and regional market

Russian fishing vessels in the early 1970s extracted and canned hake livers for regional distribution. Canning capacity is present in Walvis Bay, where pilchards and horse mackerel are currently canned.

Canning of hake livers was explored by one Namibia-based company, but the number of livers available was insufficient to make it viable. The potential local or regional market is unclear, but this can be further explored. More fruitful opportunities may arise from combining livers from multiple companies to reach a sufficient volume for canning.

It may be possible to develop livers as a value-added meal product. One option is to explore the opportunity with local food processing company African Deli, highlighted above. As stated, no fish items are in the current range; however, they process chicken livers. As such, they have experience working with livers, which have different properties to muscle proteins.

4.2.2 Global market

Fish liver oil for human consumption is a well-established supplement for its health benefits. The global cod liver oil market is projected to grow from $88.75 million in 2022 to $162.86 million by 2029 at a compound annual growth rate (CAGR) of 9.06% in the forecasted period 2022-2029.[33] This growth may provide an opportunity to process and present hake liver oil supplement as a viable alternative to cod liver oil. Livers from cod, hake and ling were found to offer the highest potential as a new source of omega-3 PUFA for human consumption. They all contain an omega-3: omega-6 PUFA ratio above 9.5, which is well above the suggested ratio of >0.5 for a healthy diet.[34]

A company based in Henties Bay, Namibia, has facilities and expertise to extrude oil from liver and make both human and pet-grade oil supplements. Their certification complies with the necessary regulations and management systems for food safety, such as Hazard Analysis and Critical Control Point (HACCP). Due to the seasonal nature of their work, they have to close for certain periods. They would be interested in exploring the opportunity to process hake livers.

4.3 By-product: hake gonads

4.3.1 Global markets

Gonads are better known by buyers and consumers as fish roe or caviar. Roe from sturgeon, salmon and trout is the most common, but hake roe is widely consumed in Spain. Some Namibian hake fishing companies are selling roe to this market. To maintain quality, one company stated that they only collect the roe during the last one or two days of catching on a fishing trip. This could be extended by using salt as a means of preservation. There is currently no publicly available data on fish roe opportunities other than caviar or salmon roe, which are not representative of markets for hake roe.

Taramasalata or taramosalata is a meze made from the salted and cured roe of cod, carp or grey mullet mixed with olive oil, lemon juice and a starchy bread base. It is eaten widely across Europe. It is unclear whether there is opportunity to use hake roe, so further investigation is required.

4.4 By-product: hake viscera

Whether used in its entirety or post-removal of the higher value by-products (for example, the liver), there is potential to direct fish viscera back into the food system, thereby reinvesting its nutritional value.

4.4.1 Fish meal input

Fish meal is a powder created by drying and powdering marine ingredients from whole fish or by-products of fish processing. Fish meal is d in developing animal feeds and is in high demand for the pig and aquaculture sectors.

Local market

While parts of the viscera provide opportunity to create higher-value products for direct human consumption (livers and gonads), fish meal plants accept fish viscera. The high moisture content necessitates considerable processing to achieve a quality input. Two fish meal plants are operating in Namibia, and both would welcome more by-product.

Global market

Fish meal is in high demand to meet increasing animal and aquafeed markets. The marine ingredient organization IFFO states that 30% of fish meal inputs come from by-products globally. Inputs to fish meal production from by-products are strongly encouraged in favour of increasing inputs from whole fish, which is limited to ensure good fisheries management. The IFFO advises that fish meal quality can be improved by separating by-products to optimize the quality and nutritional profile, as shown in Figure 11. This might allow access to higher-value markets for the fish meal.

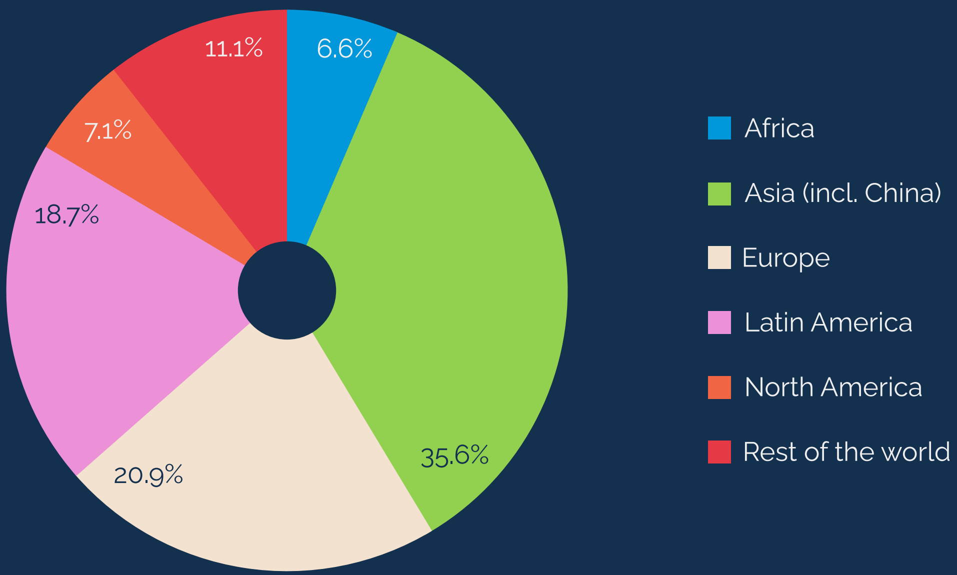
Developments along the aquaculture supply chain have helped to reduce the dependence on wild fish resources since 2000. These include the extraction of fish meal and fish oil from fish-processing waste. Figure 12 shows the amount of by-product contributing to the overall contribution from trimmings and other processing by-products.

High-valued marine salmon and shrimp typically use equal ratios of fish meal from trimmings and wild fish in their feed. Trimmings from the processing of wild fisheries now comprise roughly one-third of global fish meal production and one-half of fish meal production in Europe. Greater amounts of trimmings in fish meal have been documented, particularly in feed formulations for salmon production in Norway and for shrimp and catfish production in Thailand.[35]

Fig 11. Enhancing quality of fish meal

Source: IFFO, *The True Contribution of Marine Ingredients: Optimizing Human Nutrition Within Global Constraints*, 2022.

Fig 12. By-products marine ingredients – regional breakdown



Source: IFFO, *The True Contribution of Marine Ingredients: Optimizing Human Nutrition Within Global Constraints*, 2022.

4.4.2 Fertilizer

Fish viscera can also be used as a fertilizer to enhance agricultural production. Namibia imported NAD 326 million worth of fertilizer in 2022 and NAD 1.1 billion over the past five years.[36] Additionally, the war in Ukraine and Russia has increased the fertilizer price in Namibia by more than 50% due to restrictions on Russian product exports to Africa. This has increased food prices across the continent, and the Namibian government has publicly stated that it will welcome fertilizer donations from Russia. In response to the soaring prices, and the high demand for commercial fertilizer substitutes, some livestock farmers have even begun repurposing their waste to sell manure.

Namibia imported NAD 3.4 million worth of organic fertilizer in 2022.[37] Compared to chemical fertilizer, organic fertilizer is made from naturally occurring materials such as plants, mushrooms, algae and animal manure and uses certified techniques that have a less negative environmental impact and improve soil health. Fertilizers from fish or fish by-products are accepted, subject to individual standard requirements, by various international organic standards.

4.4.3 Cosmetic and pharmaceutical products

Depending on the size of the hake, the stomach and intestine can account for close to 50% of the viscera. These organs are high in certain enzymes, such as trypsin, which have several chemical applications.[38] Trypsin is found in various animal small intestines, including deep sea fish, and is critical for food and protein digestion. It is used to make barrier treatments that protect wounds and soft tissue from external pathogens.

When extracted, processed and put into mouth spray, trypsin can prevent and relieve common cold symptoms.[39] The manufacturers claim that using the product six times a day for 11 days destroyed 99% of the viral load in volunteers' noses and throats.[40] They also report that the enzymes are "sustainably sourced as a by-product of the fishing industry".[41] Marketed in the UK as ColdZyme, the trypsin enzymes deactivate the virus particles, inhibiting them from infecting, multiplying and spreading across cells.

Trypsin can also be applied topically. In the 1970s, Icelandic scientists noticed that local fishermen and staff had unusually soft hands, despite the harsh environment and conditions.[42] They established that trypsin had the potential to protect, nourish and heal skin and wounds. In Iceland, this is marketed as Penzim. Penzim is obtained from the North Atlantic cod and marketed as a multifunctional skin health product containing active enzymes (Penzyme).

4.5 Other by-products left at sea

This report focused on hake heads and viscera, including liver and gonads, only. However, during the study, several other by-products left at sea were highlighted as having potential market value, including monkfish, skins and frames.

Monkfish heads represent over half the weight of the fish, so there is considerable opportunity to explore the whole head value, nutrient content, cheek markets and other fish parts. Monkfish livers are a potential source of high nutrition and can be found on sale, tinned, in several countries.

Hake and monkfish skin are relatively easy by-products to handle and may present opportunities for goods at a high value, such as collagen, or lower value, like pet food treats. In Iceland, skins are transformed into fried snacks for human consumption. Fish skin leather is a growing research area, popular with high-end or niche products. Small, specialist companies often produce fish skin leather using low-impact methods. Successful models can be seen in France, Alaska and Iceland. It is unclear how much skin is available in Namibia and how suitable it might be for these product groups.

Frames are left at sea in certain cases, for example, where fish is filleted on the vessels. In some cases, these frames are attached to the swim bladder, which is an attractive product in China. In this case, the swim bladders of some species are consumed directly, whereas those of small hake are an ingredient in fast food items.

In addition, the frames may hold small pieces of flesh suitable for inclusion in fish mince. This can be used to make surimi and lower retail-value molded seafood products such as fish cakes. Some companies within the Namibian sector have experience, knowledge and access to these mince markets. Frames can also be

crushed for their content, used for mineral extraction, fertilizer and as a fish meal ingredient. The quantity of frames left at sea is not fully known.

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4.6 Marine Stewardship Council certification

It should be noted that all primary products and by-products from the Namibia hake fishery could, subject to the correct processes and licenses, carry the Marine Stewardship Council (MSC) certification label. This certification is awarded to fisheries deemed to be managed using best practice. Products originating from any part of the hake in the certified fishery might benefit from the assurance provided by the certification. For example, many retailers in European and North American markets, and increasingly in Japan, prioritize products originating from MSC fisheries. Furthermore, many feed manufacturers and aquaculture feed buyers prioritize sourcing inputs from MSC-certified fisheries.

5. Conclusion and recommendations

Seafood is an important part of global food systems because of its unique nutritional contribution, relatively low environmental impact compared to many animal proteins and its prevalent role in providing decent work to millions. The group of fish often referred to as whitefish, including hake and cod, are some of the more robust stocks, with over 70% MSC certified worldwide. Although some fisheries (with large modern vessels) capture and process heads and viscera, most routinely land headed and gutted fish, leaving those fish parts at sea.

Findings from this report suggest that significant quantities of by-product are left at sea, much of which has important nutritional profiles. All explored products have markets on land at both local and global levels. Some are currently unviable economically, while others need more research to understand their feasibility.

The market data on global and local markets suggest that the greatest opportunities for developing by-products in Namibian hake fisheries are two of the most immediately available discarded parts: heads and livers. It is critical that, as the exploration of by-product opportunity from hake heads and viscera progresses, economic viability of the fishing companies is paramount and underpins success. Furthermore, the 12,000 jobs created by the hake sector in Namibia are of critical importance and should not be threatened by changes to current operations.

Repurposing hake by-products can benefit Namibia in several ways. Not only will it reduce environmental pressure as it increases the value of caught fish, but it can also increase food security. Finally, the diversification of business gains in the seafood sector and job creation are key drivers for seafood by-product development.

5. Conclusion and recommendations

5.1 Recommendations for the Namibian hake industry

The report presents several recommendations for the Namibian hake sector, summarized below:

Livers

1. Explore the feasibility and value of local business opportunities for processing liver. For example, vacuum-packed meal products or the extrusion and production of hake oil for human consumption.

Fish heads

2. Consider a mutually beneficial partnership with NFCPT, exploring a win-win solution around the distribution of fish heads throughout Namibia.
3. Conduct detailed research into regional fish head markets in Africa.
4. Consider using surplus heat from fish meal factories to dry heads, establishing whether these would be an economically beneficial end product.
5. Explore the feasibility and value of processing heads into value-added products. For example, soups or stocks, with existing businesses or with a local start-up.
6. Explore alternative methods of using fish heads, which include crushing them for mineral extraction (calcium, magnesium, phosphorus) or using them as fertilizer for improving agricultural production. Determine whether processing is available regionally and whether it increases the value of the fish heads.

Viscera

7. Explore the implications of landing more viscera to sell to fish meal plants, considering onboard storage vessels, landing and handling at ports.
8. Explore opportunities for developing fertilizer in Namibia. Understand national policies and ambitions, national production and markets for fertilizer. Contact agriculture companies and fertilizer manufacturers to understand this market's process, costs, opportunities and potential.
9. Explore opportunities in the pharmaceutical and cosmetic industry for using hake viscera enzymes and the associated investment and research needs.

Finally, since the industry is already working together pre-competitively, the industry should consider opportunities for collaborative financing for product development, for products that require high investments in research and development and technology.

5.2 Further profiling and biometric data

This project explored a small sample of fish caught in one period early in the fishing season in two areas. While this represents an excellent indication of the quantities and nutritional profiles that may be available, a much larger sample must be undertaken to give reviewable, scientifically credible results.

In repeating this type of study, it is recommended to include the following aspects. Firstly, seafood contains numerous nutrients, including iron and zinc, which were not included in this study. Future research should investigate a wider spectrum of components to provide a full nutritional profile. This will provide a more thorough insight into the potential use of by-products, expanding across food, pharmaceutical, nutraceutical and medical sectors.

Secondly, several fish organs change over seasons, most notably the fish eggs, which are largest between July and October for the spawning period. Future studies should collect samples throughout the year to understand the varying by-product quantities and ensure that the timing of collecting these parts is most efficient.

Finally, this project only investigated the by-products of two hake species. While these results bring us a step closer to quantifying the nutrients lost at sea, it is worth noting that there are other commercially fished species harvested off Namibia. Research into different fish species that are also headed and gutted at sea, such as monkfish, is recommended. It would also be highly valuable to compare other fish species sold within similar markets to understand the differential nutritional properties of by-products from various species.

5. Conclusion and recommendations

This will indicate which by-products could be sold in pre-existing markets – for example, fish oil – and begin to show the value of bringing these products to shore.

5.3 Future research

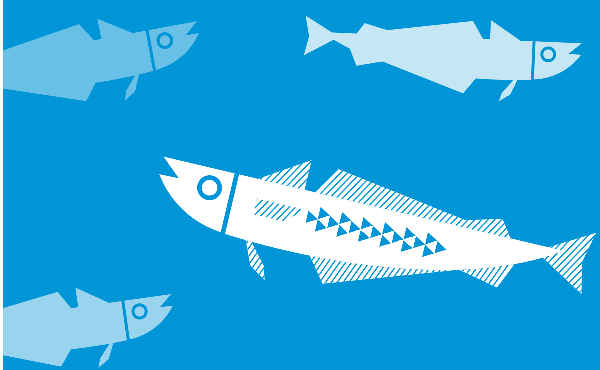
It has been raised that if vessels stopped leaving heads and viscera at sea, the ecosystems in the water column and the sea bed could be impacted. Many studies exist on the impacts on sea birds that feed on these by-products and how it can endanger them, but there is no evidence of research undertaken to understand the impact on systems below the water. This research could be pursued with the necessary authorities and academic partners in Namibia and globally.

5.4 Global outlook

This project was enabled by the agreement of the Namibian hake sector to collaborate in a pre-competitive manner. This allowed them to share knowledge and data with the support of a neutral third party. This collective approach is recommended to other fisheries interested in understanding the opportunities that seafood by-product development could pose for them.

This project represents the first global attempt to understand the amount and nutrition of by-products left at sea through primary processing on fishing vessels. The approach taken in this report can be applied to all aquatic food systems to build a global picture of the value of by-products left at sea. This will lead to a greater understanding of lost nutrition from marine food systems and can ultimately increase the value of each fish harvested as fisheries move towards using the whole fish.

Maximizing the utilization of fish requires a greater understanding of the amount and nutrition of by-products left at sea. This approach can be applied to all aquatic food systems, ultimately increasing the value and sustainability of global seafood.



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