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Mapping of Marine Rest Raw Material in the Norwegian Seafood Industry: A Decade of Results

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ABSTRACT
From 2013 to 2022, the available volumes, degree of utilization, as well as the application of different fractions of marine rest raw materials, like heads and skins, originating from the Norwegian seafood industry have been studied and mapped. The majority of the rest raw materials were still used for feed applications in 2021, but there has been observed a steady increase in volume to direct or indirect human consumption products in the period. While there are efforts to produce new high-quality products, several barriers must be addressed before a significant increase in the valorization of the industry occurs.

KEYWORDS
Rest raw material; utilization; application; fisheries; aquaculture

Introduction

With a growing world population comes a growing demand for food and new food sources, preferably without challenging the environmental sustainability. With its content of both high-quality proteins and lipids, seafood products are often referred to as one of the answers to cover the growing demand, securing future food provision (Costello et al. 2020; FAO 2022; Strøm-Andersen 2020) and reducing the high greenhouse gas production per portion protein documented for other food productions, like beef (Hilborn et al. 2018). Since the start of the 1960s and until 2019, the average rate of global fish consumption increased about 3% annually (FAO 2022). While pressure on fish stocks and various impacts on the surrounding environment have seen landings from fisheries stagnating since the 1980s, production from the global aquaculture industry has experienced a vast increase in the same period, at about 8% average annual growth (Garlock et al. 2020) or a total growth of 300% since 1990 (FAO 2022). However, as for the fisheries industry, aquaculture has various requirements like vast energy consumption, use of land, and waste discharge, all affecting the surrounding environment (Knapp and Rubino 2016). This makes greater utilization of marine raw material and rest raw material (RRM[1]), representing a massive potential for increased volumes of vital nutrients (Rustad 2002), increasingly important.

Norway has significant access to marine resources and has produced food from the oceans for literally thousands of years. This has also been the case in the last decade, with a combined volume from landings (fisheries) and production (aquaculture) ranging from about 3.2 million tons to 3.7 million tons per year (Norwegian Directorate of Fisheries 2022a). According to the Food and Agriculture Organization of the United Nations (FAO) (2022), Norway was 9th in terms of global capture producers in 2020 and 8th in terms of aquaculture production, with the seafood sector as a whole contributing to about NOK 95 billion gross domestic product in 2020 (Johansen et al.

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2021). While volumes from aquaculture have been increasing and the sector contribute strongly to economic figures, with investments in new infrastructure (Stevens et al. 2018) and increased production (Sikveland et al. 2021), there is a different story for fisheries (demersal and pelagic sector), where the major share of species and belonging volumes have reached their limits of the maximum sustainable yield (Ruiz-Salmón et al. 2020; Rustad et al. 2011; Verhagen and Ruben 2019). This is supported by statistics from The Norwegian Directorate of Fisheries (2022; 2022b), which states that the Norwegian catches in wild fisheries has ranged between 2.2 and 2.7 million tonnes since 2000, while Norwegian aquaculture production increased about 200%, to about 1.5 million tonnes, in the same period.

Utilization of RRM is not a new occurrence in Norway. The first recorded use of cod liver oil in Northern Europe was in 1783 (Curtis et al. 2004; Hjellnes et al. 2020), and cod heads have been collected for production of feed and fertilization purposes in Norway since the beginning of the 20th century (Rustad 2002). For the last thirty years, both the interest and financial support to develop overviews of and solutions for handling RRM have been growing in Norway. One of the main initiatives was the RUBIN foundation being founded in 1991 (RUBIN 2012). The founders were several different Norwegian departments, seafood member organizations, and the Research Council of Norway. From 1991 to 1998, more than 60 different projects addressing challenges and possibilities for RRM from the seafood industry were completed via the foundation. Post 1998, the motivation to continue the studies was mainly due to the large volume of RRM still being discarded from the deep-sea vessels (about 200 000 tonnes per year), as well as the promising potential to further increase the value added from the RRM in general.

With limited availability and a growing demand of marine proteins, handling of the raw material to preserve high quality before processing in a suitable and efficient way, is of the essence (Sogn-Grundvåg et al. 2022). This has been supported through the development of the Norwegian quota management system, resulting in a shift from quantity to quality (Knútsson et al. 2016; Standal and Aarset 2008), as well as a strong technological development (Al Khawli et al. 2019; Vildmyren et al. 2018), enabling willingness to pay a significant price (Sogn-Grundvåg et al. 2022) for products originating from RRM. Examples of such products are protein powder (Vildmyren et al. 2018) and collagen for the health supplement market (Subhan et al. 2021). However, while there is a vast effort from both the industry and the R&D-sector in Norway to continue the development of technology and methodologies to produce high-value products for human consumption (Digre et al. 2014; Jouvenot 2015; The Research Council of Norway 2019; Vang et al. 2020), there are often barriers preventing implementation, commonly being related to regulations, restrictions, and/or technical and economic figures (Hjellnes et al. 2020).

While there is a vast amount of RRM volume being produced without processing, like dried fish heads and back-bones originating from both fisheries and aquaculture and commonly exported to foreign markets for human consumption, there is a notable processing industry. The main processed products produced are oils (marine oils, omega-3 concentrates), proteins (fish meal, fish protein hydrolysates, marine collagen), and minerals. Marine lipids are rich in polyunsaturated fatty acids (PUFAs), especially the omega-3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These fatty acids are well-known for having a number of beneficial health effects, and seafood is a unique source (Rustad 2002; Shahidi et al. 2019). Knowing which processing options to choose depends on the preferred end-product and yield, space and man-power availability (especially on-board) (Olsen et al. 2014), and financial figures (Hjellnes et al. 2020). Today, there are three main processing technologies utilized by the fisheries and aquaculture industry for handling of RRM: silage/acid hydrolysis, production of meal and oil, and enzymatic hydrolysis (Baldursson et al. 2021).

Fish silage is produced when an acid is added to the raw material. The RRM is liquefied through the action of acid and proteolytic enzymes, resulting in a water-soluble protein phase (which contains peptides and amino acids), an oil phase, and sediments. Formic acid is the most used acid for this purpose; however, it is not suited for human consumption. In addition, the quality of the silage depends on the quality of the raw material. The process includes leaving the material for days and even weeks, which can lead to loss of quality. Therefore, silage is often used for purposes such as feed and fertilization rather than for human consumption (Toppe et al. 2018).

Compared to other options, silage is an easy technology and is time-cost effective (Hjellnes et al. 2020) but creates a low value product. In recent years, more effort has been put into increasing the quality of silage and thereby the value added. Hence, an increasing amount of fish meal in feed is now being replaced by oil and protein from silage (Olsen and Toppe 2017). Silage has a similar nutritional composition as fish meal, and when dried, it can be used for the same purposes.

Fish meal is a powder that is produced by grinding, cooking, pressing, and drying the raw material, and the fish oil is separated from the meal during cooking (Windsor 2001). Norway has large annual catches of small pelagics, like sand lance (*Ammodytes marinus*) and capelin (*Mallotus villosus*), as well as cod fishes like blue whiting (*Merlangus poutassou*) and Norway pout (*Tisopterus esmarkii*) used for production of fishmeal and fish oil. However, with the majority exported or landed in foreign countries for further processing, Norway becomes a major importer of such products (EUMOFA 2022), with its substantial fish feed industry demanding volumes.

Of almost 180 million tons of fish produced globally in 2020, about 157 million tons (89%) were used for human consumption, while about 21 million tons (11%) were utilized for non-food purposes, mainly fishmeal and fish oil. In the last decade, there has been a global increase in fishmeal and fish oil produced from RRM, reaching a share of 27% and 48%, respectively, in 2020. Lack of raw material volume from relevant species, particularly small pelagics, is the main reason for this (FAO 2022). In view of this, the share of marine ingredients in the feed composition for Atlantic salmon farmed in Norway decreased from about 90% to about 23% from 1990 to 2020, affected by both volumes and prices (Aas et al. 2022). This is supported by Misund et al. (2017), stating that the non-food use of fish oil, such as in feed production, could shrink in the future with an upswing in demand for omega-3 rich fish oil from wild fisheries for human consumption purposes, which seemingly has seen the prices increase. A similar trend has been seen for salmon oil, which is primarily utilized into premium pet food and animal feed (Liu and Dave 2022). However, Aas et al. (2022) states that a vast reduction of vital marine ingredients may interfere with growth performance and fish health of farmed fish, but the combination of new feed compositions, along with other factors related to fish farming, needs to be regularly investigated in the coming years before any firm conclusions can be given.

Enzymatic hydrolysis is a processing method using industrial enzymes added to the raw material to break it down into fish protein hydrolysates (FPH), oils, and sediment. Hydrolysate generally has great potential as functional ingredients or as added protein in food products (Remme et al. 2022). However, hydrolysates often obtain a bitter taste during processing, which is a challenge for the use for human consumption (Aspevik et al. 2021; Idowu and Benjakul 2019; Rustad 2002). In addition, the technology can be quite expensive due to the use of industrial enzymes (Hjellnes et al. 2020), and the yield is relatively low.

While pelagic species like Atlantic mackerel (*Scomber scombrus*) and Atlantic herring (*Clupea harengus*) are commonly landed whole by the Norwegian fishing fleet, there is a larger share of demersal species processed at sea, creating volumes of RRM. However, due to limited space available on-board demersal deep-sea vessels, as well as the requirement of additional manpower, on-board processing for such species is challenging (Olsen et al. 2014). Historically, RRM from demersal species has been discarded into the ocean rather than processed or stored for further utilization (Rustad et al. 2011). While national statistics have shown an increase in on-board processing of fishmeal and oil in the Norwegian deep-sea fleet in the last years, with new vessels now installing such facilities to preserve the RRM (Havfisk 2021), the volumes at about 4 000 tonnes of meal and 1 000 tonnes of oil in 2021 (Norwegian Directorate of Fisheries 2022c) is not yet comparable to land facilities in terms of volume.

Methodology

This article is based on the last 10 years of results (Olafsen et al. 2013, 2014; Richardsen et al. 2015, 2016, 2017, 2018, 2019; Myhre et al. 2020, 2021, 2022) concerning availability, degree of utilization, and application of RRM originating from the Norwegian seafood industry (*Report series*). Throughout the decade, the Norwegian Seafood Research Fund has designed the scope and funded the studies. However, they have not participated in data collection and calculations, nor written the annual reports or this article.

The methodology utilized has been constant throughout the research period, being a mix of two approaches, mainly due to data availability. The first approach utilizes official trade (seafood total), production (aquaculture), and landings (fisheries) statistics supported by official Norwegian conversion factors (CF) retrieved from the Norwegian Directorate of Fisheries, as well as conversion factors given through communication with the industry where the official ones are insufficient. This gives the opportunity of quantifying the available, non-utilized and utilized volumes of RRM. This approach is commonly known as secondary data sourcing (Hox and Boeije 2005).

Using conversion factors allows one to perform calculations from volume live weight LW to volume product weight PW, as well as the reverse. This is highly relevant for the annual studies on RRM with a vast share of statistics giving volumes in product weight, indicating a processed product where one or more RRM fractions are removed and either utilized or non-utilized. Examples of such fractions for Atlantic cod (*Gadus morhua*) can be head (about 18%), liver (about 6%), and roe (about 5%). With the Atlantic cod roe accounting for a larger share during the spawning season (January–April), the conversion factors for the species have been adjusted accordingly for volumes landed in this period. However, with no official conversion factors given for seasonal variety, there are uncertainties.

With conversion factor $CF_{PW \rightarrow LW}$ given and not from one processing state to another, one needs to multiply the volume product weight V_{PW} by the $CF_{PW \rightarrow LW}$ to find the volume live weight equivalent. Then, one multiplies by conversion factor $CF_{LW \rightarrow RRM}$ to find the available volume RRM fraction V_A.

$$V_A = V_{PW} \times CF_{PW \rightarrow LW} \times CF_{LW \rightarrow A}$$

The majority of the non-utilized volume V_{NU} RRM from the Norwegian seafood industry originates from the demersal fish sector as discards into the sea. Hence, it was decided to use the demersal fish sector as an example for explanations of further calculations; however, the calculation principle for other sectors and species are similar using the appropriate conversion factor.

While certain vessels preserve and land volumes of RRM separately after on-board processing, there are a vast share being landed attached to the main product (e.g. if only gutted, the head is landed). Hence, to calculate the non-utilized volumes RRM V_{NU}, one uses available volume V_A and subtracts by total volume RRM landed attached to the main product V_{LA} and by total volume RRM landed separately V_{SL}. An important note is that both volume RRM landed attached to the main product and separate are assumed utilized.

$$V_{NU} = V_A - (V_{LA} + V_{SL})$$

Knowing the volume RRM landed attached to the main product as well as total volume RRM landed separately, one can find the utilized volumes V_U.

$$V_U = V_A - V_{NU} = V_{LA} + V_{SL}$$

While the volume RRM landed separately is net volume RRM preserved and landed for further utilization retrieved from official landing notes, the RRM landed attached to the main product is a share of the product landed. This requires additional calculations, such as finding available volume RRM fraction. Using the appropriate conversion factor correlating to the product condition, one finds volume filet, which is not defined as RRM, and subtract from the initial landed volume. The same formula can also be used to find volume per fraction, using the specific fraction conversion factor.

$$V_{LA} = V_{PW} - (V_{PW} \times CF_{PW \to LW} \times CF_{LW \to FIL})$$

Public data on application of RRM, like human consumption or feed products, are very limited compared to trade, production, and landings data. Hence, one is dependent on significant knowledge about the industry and the belonging companies, as well as input from a sufficient number of actors to map the totality of the application of RRM, known as primary data (Hox and Boeije 2005). This is the second approach. In addition to giving significant insight into the various applications of RRM, such data also gives the opportunity to compare and validate the data from the secondary data approach in terms of available volumes of RRM, using appropriate conversion factors for the products produced.

Calculations on RRM have been done for the total seafood industry, as well as per sector: demersal fish, pelagic fisheries, aquaculture, and crustaceans. The species included in the various sector are chosen based on importance in terms of volume and value and are specified later in the article.

Results through a decade

Throughout the decade of annual reports, the structure when presenting results, similar to the methodology, has been consistent. The same structure has been adopted for this article, starting with degree of utilization in total and per sector, and then looking more into the application of the utilized volumes, divided on the three main product groups.

Utilization

From 2012 to 2021, the degree of utilization of RRM from the Norwegian seafood sector increased from 72% to 83% (Table 1), according to the *Report series*. While the pelagic sector and the aquaculture sector have registered about 100% and 93% degree of utilization over the last decade, respectively, figures for the demersal fish have been more moderate but increasing from about 35% in 2012 to 56% in 2021. The crustacean's sector is significantly smaller in terms of volume compared to the other sectors, making it harder for the few industry actors to withhold stable production. This has led to a more volatile developments in terms of degree of utilization year on year, ranging from 40% to 60% throughout the period.

The total availability of RRM for all sectors covered has ranged from about 867 000 tons to almost 1.1 million tons in the period (see Figure 1), with a degree of utilization increasing from about 72% to 83%.

Throughout the decade, the following demersal species have been included in the calculations: Atlantic cod, saithe (*Pollachius virens*), haddock (*Melanogrammus*), redfish (*Sebastes mentella*), ling (*Molva molva*), Greenland halibut (*Reinhardtius hippoglossoides*), Atlantic wolffish (*Anarhichas lupus*), and tusk (*Brosme brosme*). While results for the sector are at a lower level than the two other large sectors, there has been an increasing trend in terms of utilization, having a significant contribution to the overall positive trend in terms of utilization of RRM. The reason for the increased utilization of demersal fish RRM in the last decade is partly because of high quotas in the beginning of the decade, making onboard gutting less attractive for the large coastal fleet, resulting in higher volumes of RRM landed. Hand in hand with

Table 1. Historic development of availability and utilization of rest raw material sourced from the *Reports series.*

	2012	2016	2021
Raw material (tonnes, live weight)	3,225,000	3,278,000	3,756,000
Available RRM (tonnes)	929,000	910,000	1,090,000
Utilized RRM (tonnes)	670,000	689,000	906,000
Utilized RRM (percentage)	72%	76%	83%

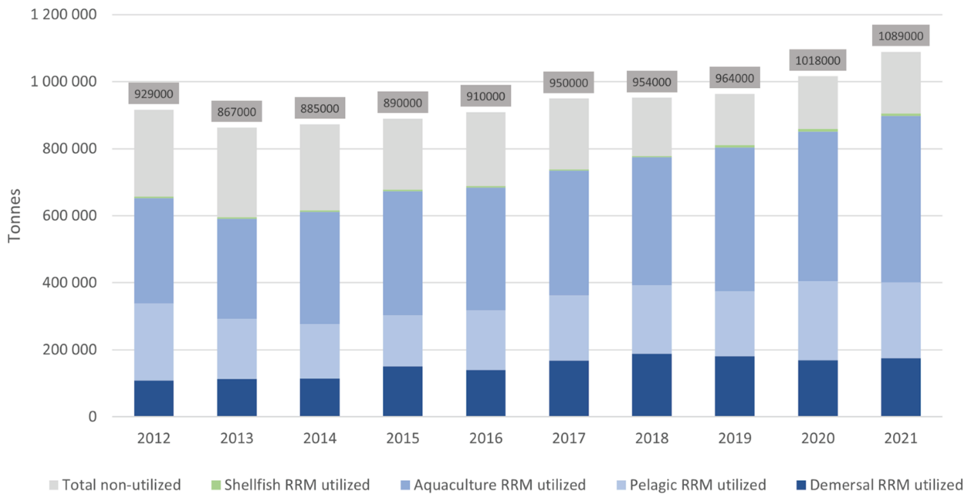

Figure 1. Historical development of total availability (on top), volume utilized per sector, and total non-utilized rest raw material, sourced from the *Report series*.

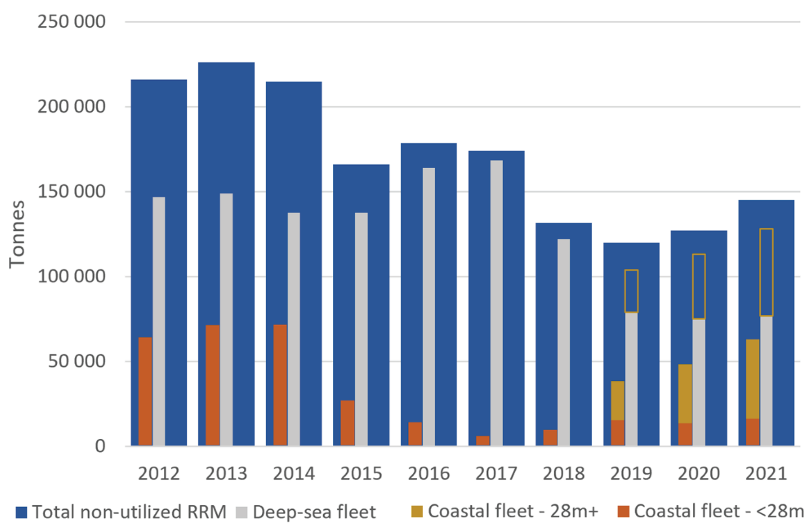

Figure 2. Historical development of non-utilized rest raw material from the Norwegian demersal deep-sea fleet[7], sourced from the *Report series.*

increased RRM availability, the attention towards utilizing more of the RRM has also grown (Arason et al. 2010; Digre et al. 2014), mainly through processing of silage and fishmeal and fish oil.

Since 2012, the majority of the discards of RRM occurred from the deep-sea vessels according to the *Report series* (see Figure 2). Commonly, trawlers with filet production and freezing preservation operates in this segment, and if installed, either silage or fishmeal and fish oil processing technologies for RRM (Grimsmo et al. 2015). However, with strict regulations on storing capacities for the specific types of vessels, based on size and type of fishery, the RRM is often less prioritized because of logistics (Hjellnes et al. 2020) and economic figures, resulting in discards of RRM representing a lower value than the primary product, i.e. filets. In the last years, 13 vessels have registered landings of processed RRM (silage and/or fishmeal and fish oil).

As for the demersal fish sector, the availability of RRM from the pelagic sector depends on the given total allowable catch (TAC) and national quotas annually, per species and zone. One example is the capelin fisheries, which was closed for Norwegian vessels in the Barents Sea between 2019 and 2021, because of observations by research cruises concluding the stock to be in a decreasing trend (ICES 2020). This resulted in a sudden absence of available capelin roe, often demanded in the sushi industry, turning the attention towards herring roe as a substitute.

The majority of RRM from pelagic species are utilized through fishmeal and fish oil production. While small pelagic fish like sand lance and capelin and cod fishes like blue whiting and Norway pout are directly utilized for fishmeal and fish oil production through reduction, there is no explicit RRM originating from these species, except capelin roe, compared to Atlantic mackerel (*Scomber scombrus*) and Atlantic herring (*Clupea harengus*), where RRM originates as cut-offs (Hilmarsdottir et al. 2021). In the last decade, the *Report series* found that the degree of utilization of RRM from the Norwegian pelagic sector landed in Norway was 100%. This has mainly been driven by the low degree of on-land processing of especially Atlantic mackerel, where the majority is exported frozen whole (about 95% both in 2020 and 2021), but also of herring (Norwegian Seafood Council 2022a).

Compared to conventional fisheries, aquaculture in Norway is a novel business that began in the late 1960s (Åm 2021). While landings of wild fish species have stagnated in the last decade, the production volume from aquaculture in Norway, dominated by Atlantic salmon but also other species like rainbow trout (*Oncorhynchus mykiss*) (Landazuri-Tveteraas et al. 2021), increased by 46% (Norwegian Directorate of Fisheries 2022b), creating more RRM available for the land industry. In 2012, about 346 000 tons of RRM was available for further utilization, while in 2020, the available volume had grown by 38% to about 477 500 tons according to the *Report series*.

While cod aquaculture was initiated at the beginning of the 2000’s, it faded out after the production peak in 2010 (Puvanendran et al. 2022), making Atlantic salmon and rainbow trout the two remaining species of significance in terms of volume RRM. In the last decade, the *Report series* found that the utilization of RRM from the aquaculture sector had been high, above 90% with only blood, originating from slaughterhouses, remaining to be used for further value added.

Compared to the other seafood sectors, the crustacean’s sector is minor in terms of volume, creating about 10 000 to 15 000 tons of available RRM per year. This is mainly originated from cold-water shrimp (*Pandalus borealis*). Because of the smaller volumes that make it difficult to establish a continuous business, the degree of utilization has fluctuated more than the other sectors, from about 40% to about 60% throughout the decade. The majority of the RRM are shrimp shells, commonly processed to meal and utilized in the feed market, with a high content of proteins, chitin, and vitamins (Jeyaprakashsabari and Aanand 2022). However, results from the *Report series* show that a growing share have been used as additives in soups and other dishes for human consumption in recent years.

Application of RRM – the three main categories

The RRM volumes originating from the Norwegian seafood sector are utilized for three main applications: (1) human consumption, (2) feed, and (3) biogas. The volume split between the three categories has been quite static throughout the years (see Figure 3).

Human consumption

Since 2012, the share of the human consumption category increased from about 10 to 13%, corresponding to about 40 000 tons to 58 000 tons. The *Report series* found that the majority (about 85%) of this was direct consumption products, which consists of less processed or prepared fractions of seafood, such as dried fish heads, salted swimming bladders, and back-bones exported to foreign markets. The remaining share was indirect products, which are commonly processed products; i.e., cod-liver oil and protein powder to be used as ingredients in functional food or in health-supplement products.

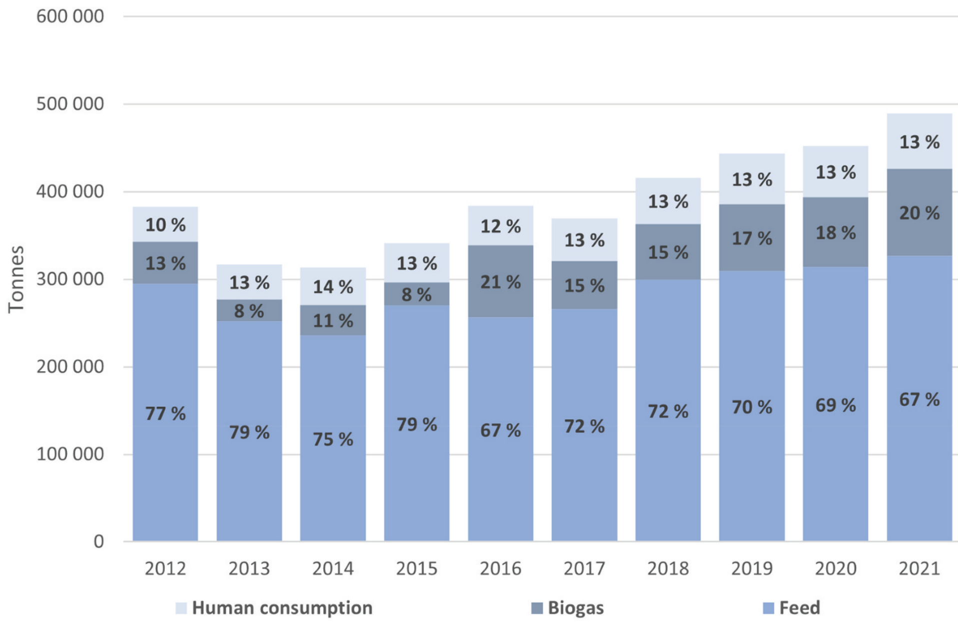

Figure 3. Historical development of main product groups originating from Norwegian rest raw material, by volume and share of total volume, sourced from the *Report series*.

According to the FAO (2022), 89% of the world production of aquatic animals from aquaculture and fisheries were used directly for human consumption in 2020. This is a noticeable difference from 67% in the 1960's. An increase of 15% (of the total tonnes produced) is expected by 2030, reaching a production of 90% for human consumption (FAO 2022). In a UN Nutrition report (2022) on aquatic foods in sustainable diets, FAO Fisheries Division presented three potential scenarios of fisheries and aquaculture in 2050. These scenarios project what the production will look like in case of a *high-road*, *low-road* or *business-as-usual* trend compared to the projections for 2030. If the trend to 2050 continues as projected to 2030 in a business-as-usual scenario, there will be a slight increase in the percentage of fisheries resources that are used for human consumption, due to improved technologies. In the high-road scenario, this percentage would decrease even more, while in the low-road scenario it would stay about the same as in 2030 (Ahern et al. 2021).

In line with the *high* and *business-as-usual* scenarios, several R&D organizations have researched new methods for increasing the value added of RRM in the recent years, in particular for human consumption purposes. Cod heads, which conventionally have been exported dry to foreign markets for human consumption, in particular Nigeria (Norwegian Seafood Council 2022b), is one example. The main driver for this was the Nigerian market experiencing challenges in terms of currency devaluation over the last years (Liverpool-Tasie et al. 2021), leading to reduced purchasing power that created significant uncertainty for the producers and exporters, demanding more predictability. This could also increase the attractiveness of preserving and landing more volumes of demersal fish heads, in particular cod, which are currently the largest volume fraction non-utilized of RRM in total.

Cod heads, accounting for about 20% of the live fish weight and about 43% of the RRM (Hjellnes et al. 2020; Tveit et al. 2020), contains a high degree of protein (up to 15%) and a low level of lipids (about 4%). Remme et al. (2022) demonstrated that cod heads are a good source for the production of high-quality fish protein hydrolysates for human consumption, and such ingredients can contribute to reduced blood pressure activity (Hjellnes et al. 2021). According to Vang et al. (2020), after consolidating with the industry, high-quality FPH can achieve a market price at about 100 NOK/kg and even higher if the availability and quality is constant.

Feed

Results from the *Report series* show that the majority of the Norwegian volumes are downgraded from RRM to by-products, meaning they cannot be used for human consumption applications. This is according to the EU regulation regarding utilization of various products in terms of their condition (European Union 2009), which was developed in response to avoid occurrences like the bovine spongiform encephalopathy (BSE) or mad cow disease (Parker 2018). Reasons for this are the economic figures and the low sensory quality not achieving consumer acceptance (Ozogul et al. 2021). Animal by-products are classified into three different categories. Categories 1 and 2 are high risk and have less application options (e.g., combustion (cat 1), feed for fur-animals (cat 2) and biogas (cat 2)), while category 3 is low risk and can be used as ingredients in a higher number of applications, such as feed for food-producing animals (Lovdata 2016).

In the last decade, the *Report series* found that about 70 to 80%, or about 240 000 tons to 315 000 tons, of the total RRM have been utilized for feed purposes. The majority of this, about 50 to 60%, has been utilized for fish feed, mainly for production of feed for domestic production of salmonids but also for other European species such as sea bass and sea bream produced in the Mediterranean area. Similar to Norway, the global aquaculture industry consumed the majority of the available fishmeal (86%) and fish oil (73%) in 2020 (FAO 2022), mainly originating from marine forage fish species (Hua et al. 2019; Quang Tran et al. 2022) but also RRM, estimated to account for about one-third of the volume (IFFO 2020).

The second largest feed market for Norwegian RRM is feed for the agriculture industry, where volumes have been stable at around 60 000 to 70 000 tonnes through the years. Meanwhile, the pet food market, ranking third in volume, has seen an increase from about 15 000 tonnes to about 44 000 tonnes, driven by the increasing ownership of pets and general concern for their well-being (García-Vaquero 2018; Hjellnes et al. 2020).

While the fur animal market had significant shares of RRM volumes at the start of the decade, the recent years have shown a decreasing trend. This is mainly due to Norway forbidding farming of fur animals for the purpose of fur from 2025 (Henriksen et al. 2022), as well as significant COVID-19 breakouts in mink farms in Denmark in 2020 (Larsen et al. 2021). According to the *Report series*, it is expected that this market will remain small or even disappear in the coming years.

Biogas

According to Cristiano et al. (2022), fish mortality and discards are significant by-products in the aquaculture industry. This is supported by the *Report series*, finding such volumes increasing as the production of salmonids in Norway has increased throughout the decade, mainly due to salmon lice (Overton et al. 2019), diseases (Barrett et al. 2022), or other handling operations. Being in its respective condition following such incidents, it is regulated as category 2 material following the EU regulation (European Union 2009) and is suitable for a limited amount of applications including biogas production and feed ingredient for fur animals.

With a recent decline in volumes produced for fur-animal feed, in addition to the increased production volumes in aquaculture, RRM for biogas production has increased steadily through the decade, from about 30 000–40 000 tons to almost 100 000 tons in 2021. While the majority of the volumes have ended up in foreign production facilities in the last decade, a recent development in the domestic industry has seen production increase in recent years (Lyng et al. 2020). While the *Report series* has not included sludge, there are significant volumes available from the aquaculture sector, in the form of carbon, nitrogen, and phosphor that are not utilized today (Hilmarsen et al. 2020). With such volumes defined as category 2 material (Sarker 2020), it can create additional volumes for the growing biogas production industry in Norway in the coming years.

Barriers

With a growing focus on the utilization of resources, international and national initiatives and future strategies have emerged in the last decades, like the overarching UN SDGs, including target 12.2 *sustainable management and use of natural resources* (United Nations 2022) and *Europe 2020 strategy* (European Union 2010), including its flagship initiative: *A resource-efficient Europe* (European Union 2011). Norway has shown engagement as well, stating various future goals for the blue economy including sustainable utilization of ocean resources for increased value added in local communities (Ministry of Industry and Fisheries 2019). This makes sense with the knowledge that a vast volume of RRM that is discarded today contains significant shares of amino acids, vitamins, and minerals, such as magnesium, phosphorus, and calcium (Elvevoll and James 2001; Hjellnes et al. 2020) which, depending on the functional and structural characteristics, can be used as additives or ingredients in various high-value markets into food or health supplement products (Ozogul et al. 2021). However, while the mapping of the degree of utilization and application of RRM from the Norwegian seafood industry has shown a positive trend in the last decade, there are various barriers that need to be addressed to increase the value added further in the coming years.

The majority of the non-utilized RRM can be located in the demersal fish sector (discards), especially in the deep-sea fleet. In theory, an easy solution would be to create a landing obligation making the fishermen land all volumes, including the RRM fractions like fish heads and viscera. In practice, however, this is not an easy solution. With a limited amount of available space of use on-board the vessels, handling of primary products achieving a significantly higher price would be affected by installments of processing and storage facilities for RRM, which also represents additional investment and production cost. Replacing storage capacity with RRM products will also mean additional trips needed to complete the quota, increasing the fuel consumption (Hjellnes et al. 2020).

While the aquaculture sector achieved more than 90% degree of utilization of the RRM in the last decade, there have not been any solutions for utilization of the remaining volumes: blood originating in the slaughterhouses. Nordtvedt et al. (2015) studied cleaning of the process water, including blood, in lab-scale, and concluded that filtration and centrifugation can be sufficient to achieve appropriate cleaning level for bacterial control. However, the technology is still not commercialized, and new studies are running today to continue the hunt for suitable solutions.

A solution to avoid significant investment risks for the companies is to create national test facilities through public R&D-funding (Tveiterås et al. 2022). This can be a step in the right direction with a vast share of present research limited to lab-scale, mainly due to outdated infrastructure in the industry (Vang and Lian 2021). Tveiterås et al. (2022) also suggests creating a digital guidance document on handling options, documentation, and classification of new species and products concerning processing and market access. This would reduce the need for individual companies to create a new knowledge base for the numerous amounts of regulations and certifications needed for the various products from RRM (Vang and Lian 2021), which can often be a barrier (Strøm-Andersen 2020) preventing establishment of new value chains and products.

Solving some of the technical and economic barriers, as well as adapting regulatory policies, can contribute to an increased utilization and value added from Norwegian RRM. However, such volumes are minor compared to the RRM being exported, mainly to the EU, attached to the primary product. This is mainly driven by high production costs and customs duties on processed products in important markets (Olafsdottir et al. 2019). For example, in 2021, about 83% or more than 1 million tonnes of farmed Atlantic salmon were exported from Norway as fresh gutted, head-on (Norwegian Seafood Council 2022c). This resulted in limited domestic availability of RRM, like heads and backs, as well as skins that are increasingly demanded because of the potential source of collagen and its hydrolysis product gelatin, commonly used as health supplement, pharmaceutical, or cosmetics (Välimaa et al. 2019). The limited availability is also reflected in Pleym et al. (2019), where the Norwegian marine ingredient industry reported availability as the main challenge in addition to market access. The lack of availability forces companies to import RRM, often from other European countries to cover the necessary volume needed to be profitable. In many cases, such volumes have Norwegian origin, with Norway having a 25% volume share of EU imports of seafood in 2021 (EUMOFA 2022a). Pleym et al. (2019) also found that companies targeting a specific product category, with fish protein concentrate or fish oil achieving the best financial results, compared to other companies targeting a combination of products.

If one also solves the availability barrier, creating well established value chains domestically, one could see a more stable and profitable marine ingredient industry than in recent time where there has been a high degree of replacement.

Conclusion

Having significant shares of proteins, lipids, and minerals, RRM from seafood can be a part of the solution to cover the global food and feed demand in the future. Simultaneously, by utilizing such resources, one can avoid using additional areas on land for food production. In Norway, increasing attention towards higher utilization and increased value added from the RRM have occurred in the recent decade. While the pelagic sector has reached 100% utilization of the available RRM volumes, the aquaculture sector, dominated by Atlantic salmon has been steady at more than 90%. In comparison, the demersal sector has been significantly lower in the percentage utilized, at around 50–60% in the last years, but experienced a noticeable increase since 2012 when it registered about 35% utilization of available volumes. The majority of the non-utilized volumes occurs in the deep-sea fleet.

However, a vast increase in effort from both the industry and the R&D sector, pushed by international and national initiatives and strategies throughout the last decade, creates a positive outlook for the future in terms of increased utilization of the available volumes RRM in the demersal sector. Creating national industry test-labs will reduce risks concerning instalments on board deep-sea vessels, and products created and guidance documents can support increased market knowledge. Such initiatives can have a vital role in establishing economic viable value chains, which often has been addressed as a main issue for preservation and landing of the volumes.

Through the *Report series*, the industry, R&D, and national authorities gain access to follow the development of Norwegian RRM in terms of available volumes, market development, as well as understanding critical points where improvements are necessary. Hopefully, this article can inspire other countries to establish similar overviews in the future, increasing the utilization and value added from an increasingly important resource in the years to come.

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Data availability statement

The research data associated with this paper is available through annual PDF-reports in Norwegian at the home page of the Norwegian Seafood Research Fund (https://www.fhf.no/). Using the key words *marint restråstoff* in the search engine at the home page will list the various project periods, with the associated annual reports (including data).

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