

AQUACULTURE

Spatial distribution of fishmeal and fish oil factories around the globe

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Fishmeal and fish oil (FMFO) are critical inputs for the compound aquatic feeds sustaining the fed aquaculture sector, yet there is limited publicly available information on the location of FMFO production factories around the globe. This makes it difficult to assess the environmental, social, and economic impacts of individual factories and the industry's footprint as a whole. To fill this knowledge gap, we compiled location data for FMFO factories across 63 producing countries. We identified 506 factories owned and/or operated by 413 companies. We provide an open-source database that includes FMFO factory locations, company names, and raw material types. This study offers a first look at the spatial distribution of the FMFO industry and serves as a valuable resource for marine resource managers and policymakers. Knowing the locations of factories and where FMFO production is concentrated can inform the development of cooperative national and international policies to ensure environmentally and socially responsible standards.

INTRODUCTION

Wild fisheries catch is declining, and much hope is pinned on the aquaculture industry to meet growing seafood demand (1). However, many of the fish species that are produced and considered desirable by people in high-income countries, for example, Atlantic salmon, are carnivorous [approximately 63 million tonnes in 2020 (2)] and need to be fed with other fish. To meet fish nutrition requirements, aquatic feeds often contain fishmeal and fish oil (FMFO) ingredients (3). In 2022, the State of World Fisheries and Aquaculture report found that 86% of FM and 73% of FO were directed toward aquaculture. Meanwhile, the global supply of FMFO has plateaued as the demand, and consequently the price, of FMFO have grown (4).

FMFO can be produced using whole fish and/or fish processing waste (e.g., heads and tails from canning operations). However, to date, a large proportion of raw materials for FM (66%) and FO (47%) still originate from wild capture, small pelagic fisheries (5)—the so-called forage fisheries (6). This practice is controversial for three main reasons. First, capturing fish to produce aquaculture feed threatens marine ecosystems by, for instance, increasing demand for fishing on wild fish populations that could exacerbate overfishing (6, 7). Second, diverting wild fish from human consumption to feed aquaculture undermines human food and nutrition security of low-income people all over the world (8–10). Third, the globalization of FMFO trade has resulted in lower traceability of aquatic feed inputs (11). This points to an important question raised by Naylor *et al.* (11): “How should forage fish resources be allocated among competing uses: to the highest economic value (e.g., ranched bluefin tuna), to feeding the largest number of people, or to conserving natural ecosystems (11)?”

FMFO are critical to the fed aquaculture sector due to their unique nutrient profile, palatability (which enhances appetite and thus growth) (12), and high protein content, which are required to grow fish to market size (13). Fishmeal is particularly rich in protein,

with a much higher protein to meal ratio compared to plant-based alternatives (14). Moreover, plant-based proteins, such as soybean meal, may contain antinutritional factors that negatively affect the intestinal microbiota and immunity of carnivorous aquaculture species, further limiting the ability to fully replace fishmeal with vegetable proteins (15). Aquaculture species can also have higher lipid requirements than terrestrial farm animals. This explains why fish oil, which contains high levels of key lipid classes including omega-3 long-chain polyunsaturated fatty acids [eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)], is essential for the growth and nutrition of fish and must be included in a fish's diet as they cannot synthesize these fatty acids themselves (4, 16).

The need for key nutrients in aquatic feeds has diverted millions of tonnes of nutritious fish away from countries with high rates of nutrition insecurity (8, 17, 18). FMFO factories have been shown to compete with nearby communities for fish access, resulting in increased fish prices and depletion of fish stocks (5, 19)—stocks that are in turn diverted toward farmed fish meant for luxury markets (20). Farmed Atlantic salmon, for example, is a major consumer of FMFO and substantial contributor to the expansion of the global aquatic products trade (5). This is of particular concern given that small pelagic fishes are a vital source of affordable nutrition in many coastal emerging economies, such as those in West Africa and Southeast Asia (21). Notably, one study found that if Peruvian anchovy (*Engraulis ringens*), the largest fishery by weight in the world, were directed toward direct human consumption rather than FMFO production, then it could eradicate severe malnutrition in children globally (9).

While studies have addressed the efficacy of using whole fish for FMFO production and how this production should be prioritized (7, 8, 21, 22), there has been limited research on the production landscape, for example, where FMFO factories are located, which species of fish the factories are consuming, and factory ownership. This type of information is critical chiefly because of the implications for local and regional food (in)security mentioned above. It is also relevant because factories can have notable localized environmental effects on the communities in which they are located (19, 23, 24). For example, they may contribute to air and water pollution. The cooking and drying

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of fish during FMFO production generates substantial emissions of particulate matter, nitrogen oxides, sulfur oxides, and hydrogen sulfides, as well as high odor levels from excess trimethylamines (25). One recent report by the Changing Markets Foundation documented numerous accounts of pollution and environmental degradation in Peru's FMFO industry, including untreated wastewater dumping and decreased air quality (26). Understanding the spatial distribution of factories helps to identify hotspots where these impacts are most pronounced, allowing for targeted mitigation and management strategies.

In addition, as fish stocks shift due to climate change, the geographic location of factories within a country or region will influence their ability to continue operating, with impacts on local economies. Temperature-driven shifts in fish stocks have already been seen in West Africa (27), where FMFO factories are located up and down the coast. Mapping the factory locations provides a baseline for understanding how these shifts in fish stocks might affect the industry and local communities over time.

With the aquaculture sector projected to expand, demand for FMFO will continue (2). For example, between 2000 and 2021, the fed aquaculture industry doubled its intake of fishmeal (2). Moreover, between 2021 and 2022, fed aquaculture production continued to outpace nonfed aquaculture production, reflecting the rapid and sustained growth of the sector (5). To address sustainability, equity, and conservation concerns associated with this industry, it is essential to develop robust policies for its effective governance and management. Having an accurate and comprehensive spatial database of FMFO factories is important to understand the development of this industry as well as support the monitoring of factories' activities, including compliance with environmental and labor standards. This is particularly important in contexts where fisheries governance is weak. To support these efforts, this study maps the distribution of FMFO factories, providing a critical first step in assessing the industry's global footprint.

RESULTS

FMFO companies and their factories

We identified 506 individual FMFO factories located in 63 countries (Fig. 1 and data S1). These factories are owned and/or operated by

413 companies. Of these, 63% had known locations verified using satellite imagery and company website information (data type A, Table 1). The remaining 37% were missing specific location information and/or could not be verified using satellite imagery (data types B, C, or D).

Peru had the highest number of FMFO factories ($n = 125$), followed by Mauritania ($n = 42$) and Chile ($n = 33$). For both Peru and Mauritania, the national fisheries departments published lists of recognized FMFO factories with company names and site addresses, which greatly facilitated their inclusion in our dataset. Only one other country, New Zealand, provided a similar published list of FMFO factories within its borders. Conversely, no company names or factory locations could be found for Belarus, Cameroon, and Guinea.

Most companies/factories were found using publicly available member lists from the The Marine Ingredients Organisation (IFFO) and MarinTrust. The latter was particularly useful because company certificates were available for download and included the factory address and detailed information regarding raw material inputs. Information on production capacity for individual factories was typically not available on company websites or national datasets, except for Peru.

Raw materials

Information on raw material inputs (i.e., whole fish or by-products) was available for 377 factories (75% of total). Species data, to the functional group level, were only available for 298 factories (59%). By-products were the most common single raw material used by factories (49%), with whole fish as the primary source of raw material for 37% of factories (Fig. 2A). The remaining factories (14%) used both whole fish and by-products. The majority of companies (60%) sourcing whole fish as raw material for FMFO production relied on small pelagics (<30 cm). By-products on the other hand were sourced from a greater diversity of species (Fig. 3). By-products mostly not only originated from capture fisheries waste but also included aquaculture waste (Fig. 2B). Note that these results do not account for production quantity due to limited available information.

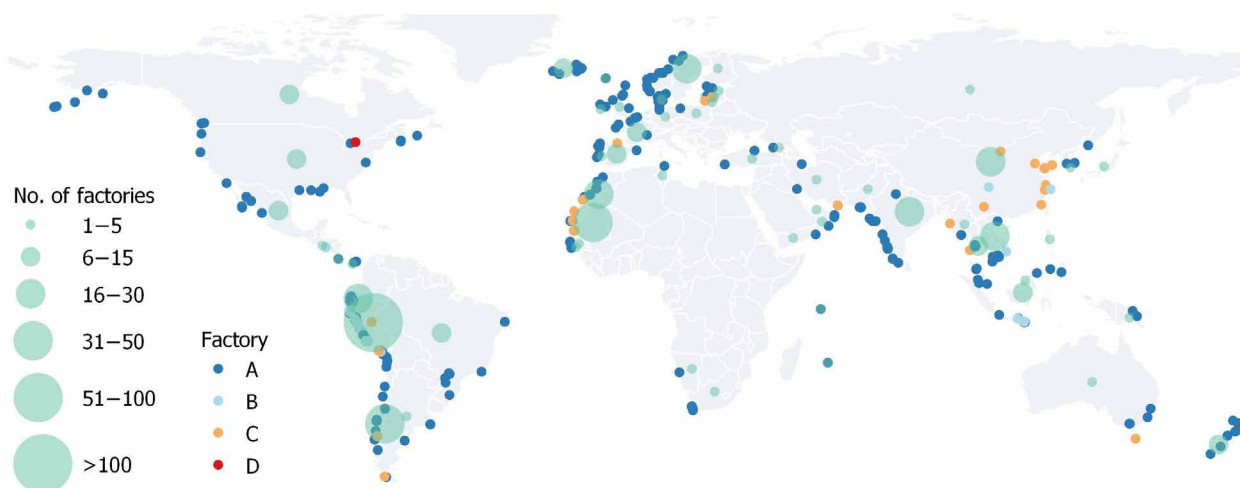


Fig. 1. Spatial distribution of factories. Factories are color-coded by data type (see Table 1). Factories in dark blue (data type A) represent plants whose locations we were able to verify using satellite imagery and company website information. Green shaded circles represent and are scaled to the number of factories per producing country.

Table 1. Data types. Descriptions for the data types assigned to each unique FMFO factory.	
Data type	Description
A	Factory location verified using the Google Maps satellite image layer. Factory address published on company website, provided by third-party source (e.g., MarinTrust certificate), or an active “business” pin on Google Maps.
B	Factory address published on company website or by a third-party source but not verified using satellite image layer. Address was geocoded using the open-source Geocode.xyz platform, and the geocode confidence score was greater than 0.5.
C	The city or province in which the factory is located is known, and the coordinates for the city/province are used or the geocode confidence score for the address is 0.5 or below (typically depicting that the address could only be matched to the city/province level).
D	Only the country in which the factory is located is known.

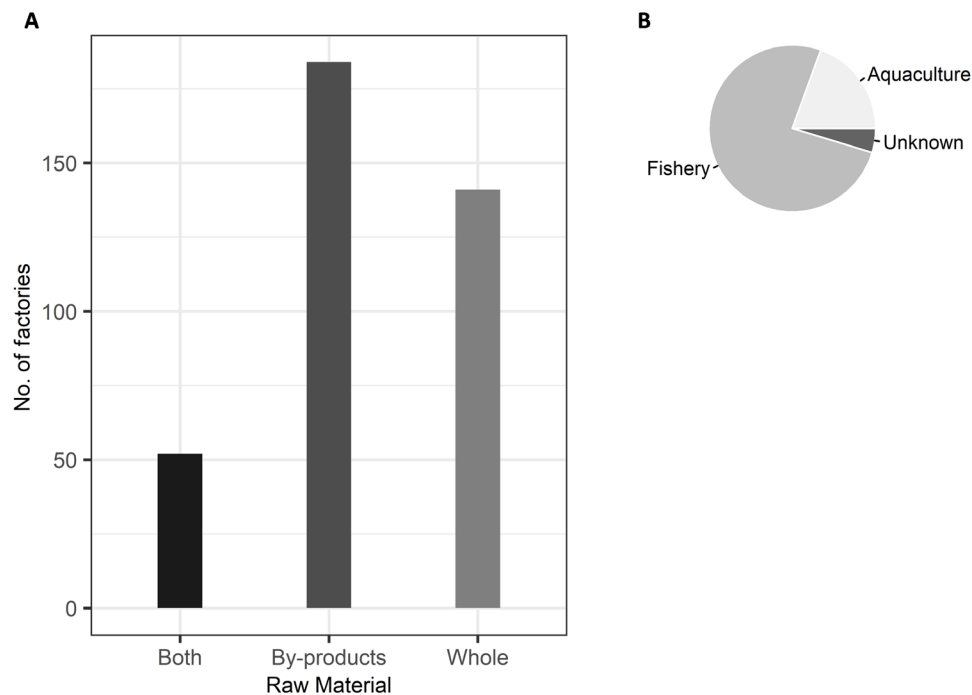


Fig. 2. Source of raw materials used by factories to produce FMFO. (A) Number of factories using whole fish, by-products, or both as raw materials. To avoid double counting, factories that sourced whole fish and by-products were categorized under “both.” (B) By-products category is further classified according to their source (fishery, aquaculture, or unknown).

Global FMFO production

Production data for the 63 countries included in this study (Fig. 4) were used to calculate the ratio of fishmeal to fish oil production for each country (Table 2). This ratio is variable, ranging among the top 20 producers between 17.8 and 1.1 (Table 2 and Fig. 5).

FMFO factories and fed aquaculture production

Lastly, we compared the FMFO factory locations to the fed aquaculture production values for each country provided by (28) (Fig. 6). While (28) found that China had the highest levels of fed aquaculture production, followed by Norway and Indonesia, our results show that these countries ranked 4th, 8th, and 23rd, respectively, in FMFO production.

DISCUSSION

Key findings

Through the collection of the data reported in this paper, we generated a map detailing known FMFO factory locations for 63 countries

globally. We also gathered information on the raw materials used as inputs, i.e., whole fish or by-products, by these factories for FMFO production. Our database and findings provide a valuable foundation to understand the industry’s spatial distribution and to identify data gaps. Our results can be used in further studies on the trade of marine ingredients and provide vital information for analyses into the environmental, social, and economic impacts of FMFO factories, with a view to inform the implementation of effective policies in support of responsible FMFO production and use.

We were surprised to find that most factories are using fishery and/or aquaculture by-products as raw material for the production of FMFO rather than whole fish. However, as mentioned previously when considering production quantity, a larger proportion of FMFO still originates from whole fish. This is an important consideration for policymakers trying to better manage the FMFO industry. When fish by-products are converted into FMFO in a transparent and well-regulated manner, it can represent an efficient waste-management strategy (5, 29, 30). For example, the European

Table 2. Production of FMFO by country in 2022. FM, fishmeal; FO, fish oil. Data source for production quantities: IFFO.				
Country	FM production (000 metric ton)	FO production (000 metric ton)	Ratio (FM: FO)	No. of factories
Peru	1003.36	100.33	10.0	125
China	400.46	56.07	7.1	22
Chile	378.60	150.93	2.5	33
Vietnam	352.06	179.00	2.0	16
India	347.17	63.45	5.5	23
Thailand	285.36	33.78	8.4	12
United States	237.70	87.84	2.7	13
Japan	202.50	68.58	3.0	3
Norway	184.72	126.69	1.5	17
Morocco	176.45	47.17	3.7	16
Iceland	162.60	68.80	2.4	10
Denmark	148.81	45.67	3.3	5
Mexico	135.00	29.89	4.5	11
Russia	129.61	6.70	19.4	2
Ecuador	117.75	14.90	7.9	18
Mauritania	91.95	21.32	4.3	42
Faroe Islands	65.88	24.76	2.7	1
Brazil	65.57	8.52	7.7	8
Pakistan	62.00	6.20	10.0	3
South Africa	60.39	11.35	5.3	5
Myanmar	50.00	6.50	7.7	4
Indonesia	49.28	4.73	10.4	11
Spain	46.35	10.42	4.4	5
Oman	45.22	8.19	5.5	5
Philippines	37.86	4.86	7.8	2
Malaysia	37.11	3.71	10.0	4
New Zealand	32.00	1.80	17.8	10
Iran	30.00	4.00	7.5	3
United Kingdom	22.73	7.95	2.9	6
Germany	22.52	13.15	1.7	3
Turkey	22.50	18.75	1.2	4
Panama	22.00	3.59	6.1	2
South Korea	20.80	3.40	6.1	2
Argentina	18.44	0.90	20.5	4
Taiwan	18.00	0.70	25.7	1
France	17.71	9.92	1.8	6
Latvia	16.20	11.50	1.4	5
Ireland	14.08	2.08	6.8	3
Lithuania	12.50	1.80	6.9	1
Estonia	12.30	3.00	4.1	1
Georgia	12.00	10.00	1.2	1
Portugal	12.00	1.10	10.9	2
Senegal	11.50	2.50	4.6	2
Poland	10.75	7.50	1.4	1
Mauritius	10.55	0.90	11.7	1
Australia	8.25	3.09	2.7	5
Papua New Guinea	8.00	1.04	7.7	2
Tunisia	7.28	0.60	12.1	2
(Continued)				

(Continued)

Country	FM production (000 metric ton)	FO production (000 metric ton)	Ratio (FM: FO)	No. of factories
Cameroon	7.00	1.50	4.7	0
El Salvador	7.00	0.50	14.0	1
Kazakhstan	7.00	0.50	14.0	1
Samoa	6.50	0.85	7.7	1
Namibia	6.00	1.00	6.0	1
Finland	5.42	1.80	3.0	1
Seychelles	5.00	0.65	7.7	1
Yemen	4.50	1.00	4.5	4
Canada	4.45	4.18	1.1	7
Gambia	4.00	6.50	0.6	3
Costa Rica	3.00	1.00	3.0	1
Belarus	2.00	0.50	4.0	0
Slovakia	2.00	0.60	3.3	1
United Arab Emirates	2.00	0.50	4.0	2
Guinea	0.00	1.50	0.0	0

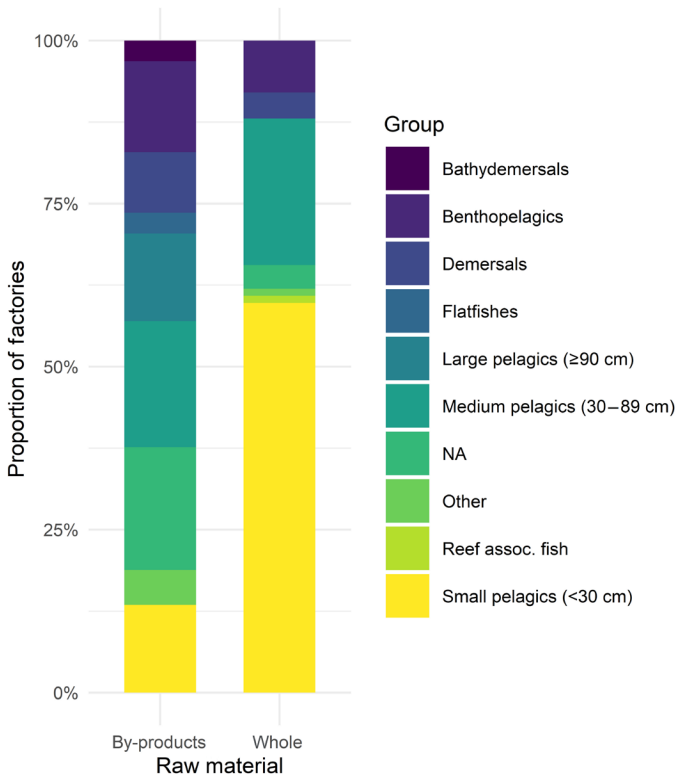


Fig. 3. Whole fish and fish by-product materials classified by species’ functional groups.

Fishmeal and Fish Oil Producers (EFFOP) advocate for the use of fish by-products in member FMFO production to reduce waste and increase recycling, as up to 60% of a fresh fish may be discarded during filleting (31). However, it is critical to ensure that this process

does not inadvertently incentivize unsustainable fishing practices. In contrast, the use of whole fish to produce FMFO can raise concerns, particularly when these fish are species that are typically consumed by local communities or play an important role in nutrition security (32). The impacts of FMFO production depend heavily on local contexts, including the extent to which communities rely on fish for food or livelihoods, the availability of fisheries data, and the health and management of local stocks.

Our findings also show that the number of FMFO factories in a given country is not an indicator of FMFO production. Factories vary in their production capacities based on the technologies they use. For instance, European countries—including Norway, Denmark, and Ireland—have few factories, but these achieve high production levels. Although FM and FO are coproducts, we found high variability across country-level FM:FO ratios. This variability may stem from several factors. It could be the result of differences in the costs and equipment used for producing FO in a given country. It is likely also dependent on the lipid content of raw materials used, with some species being higher in oil content than others. Some have also posited that environmental conditions, notably temperature, may influence fatty acid content in fish, leading to differences in the yield and quality of oil extracted (33). Recent work on freshwater fish shows that phylogenetic factors strongly influence their fatty acid composition and omega-3 content and that the response of EPA and DHA content in fish to temperature variations may be species specific (33). The refining processes used to produce fish oil can further influence the amount of oil that is extracted from fish and its quality (34).

Study limitations

We acknowledge that despite our best efforts to compile data from official statistics, industry representatives, and available literature, there are gaps in coverage. Several major producing countries, most importantly, China, are not well represented. Reasons for

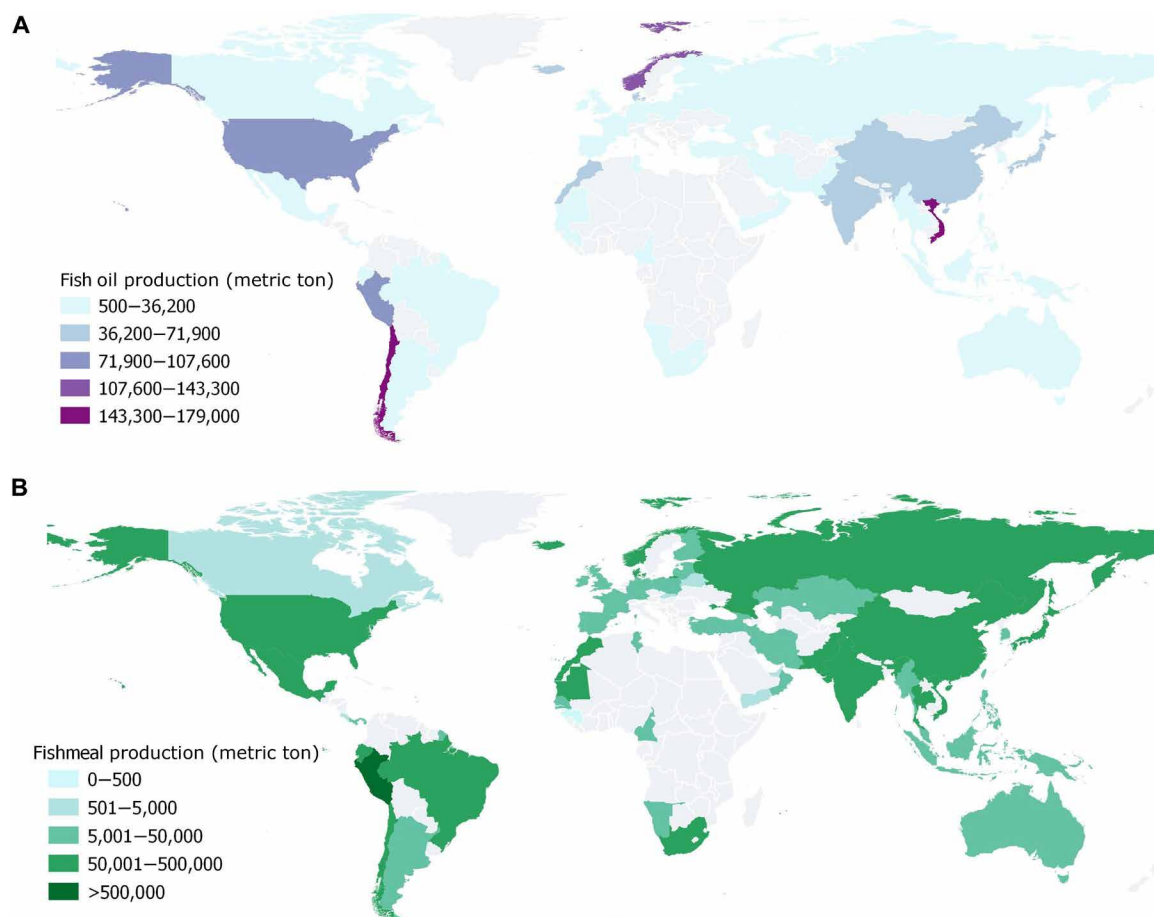


Fig. 4. Global maps with countries shaded by production quantity (metric tons) of fishmeal and fish oil in 2022. (A) displays fish oil production and (B), fishmeal production. Darker colors correspond to higher levels of production. Data source: IFFO.

these data gaps include the language used in web-based searches, a lack of national reporting, and the limited online presence of FMFO production companies. In Senegal, some reports suggest that seven FMFO factories are operational, but only two factories were located in Senegal and included. This discrepancy may result from limitations in data accessibility, differences in definitions of “operational” factories, or delays in updates to publicly available sources. Countries with well-established regulatory frameworks and/or regularly updated databases—such as Norway, Peru, or Mauritania—have more readily accessible data and are therefore better represented. Conversely, regions where data-sharing practices are less formalized or where this information is not consistently documented may be underrepresented. Most of our data collection efforts relied on information published by organizations such as IFFO and MarinTrust, membership to which requires considerable fees and proof of capacity for membership.

In addition, this study focused on FMFO producers/factories rather than aquatic feed companies. This is an important distinction because aquaculture species are typically not fed FMFO directly. Rather, FMFO are two key ingredients included in compound aquatic feeds formulated by feed companies (35). Feed producers are an important link between the FMFO producers and aquaculture farms but were not included in this study due to time and resource availability.

Next steps

Collecting these data was both time and resource intensive. While we made concerted efforts to reach out to experts in various regions to verify and supplement the data, we were limited in the time and resources available to identify and engage with a broader range of experts or to allow for extended response times. This limitation underscores the need for ongoing collaboration with regional stakeholders and experts to refine and expand the database, ensuring more comprehensive and equitable coverage across all regions.

Given the dynamic nature of the sector, it is important to regularly update this database to maintain its relevance and accuracy. Better data availability is crucial for understanding the footprint of the FMFO industry and assessing its impacts at local, regional, and global scales. We therefore urge all major FMFO-producing countries to officially report information on the following:

- 1) Location: Precise geographical coordinates or addresses of operational factories.
- 2) Year in operation: To track historical trends and identify newly established or closing factories.
- 3) Species processed: Including quantities and whether fish are used whole or as by-products.
- 4) Total production: Data for FMFO and the species used for each.
- 5) Conversion rates: Tonnes of fish required to produce FMFO.
- 6) Disclosure of certifications obtained, e.g., MarinTrust.

7) Information on regulatory compliance.

One mechanism that is well-positioned to provide guidance to countries on fisheries reporting and transparency frameworks is the Fisheries Transparency Initiative (FiTI), an internationally recognized framework on what fisheries information should be published online by governments (36). For example, FiTI members are required to publish information on the post-harvest sector and fish trade. Section B.1.7 of The FiTI Standard (2017) includes: (i) total quantity of fish and fish products produced, disaggregated by species and fish products; (ii) total quantity of imports of fish and fish products, disaggregated by species and fish products, indicating the country of their origin; and (iii) total quantities of exports of fish and fish products, disaggregated by species and fish products,

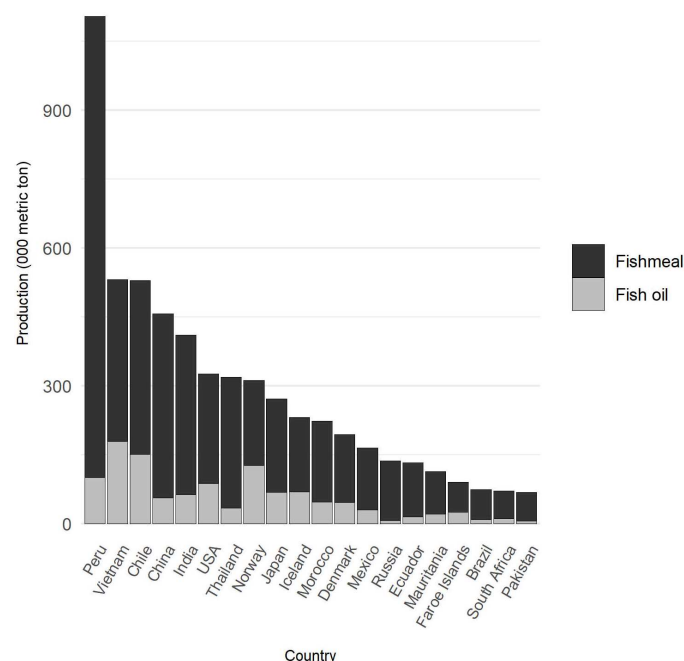


Fig. 5. FMFO production for the top 20 producing countries in 2022. Data source: IFFO.

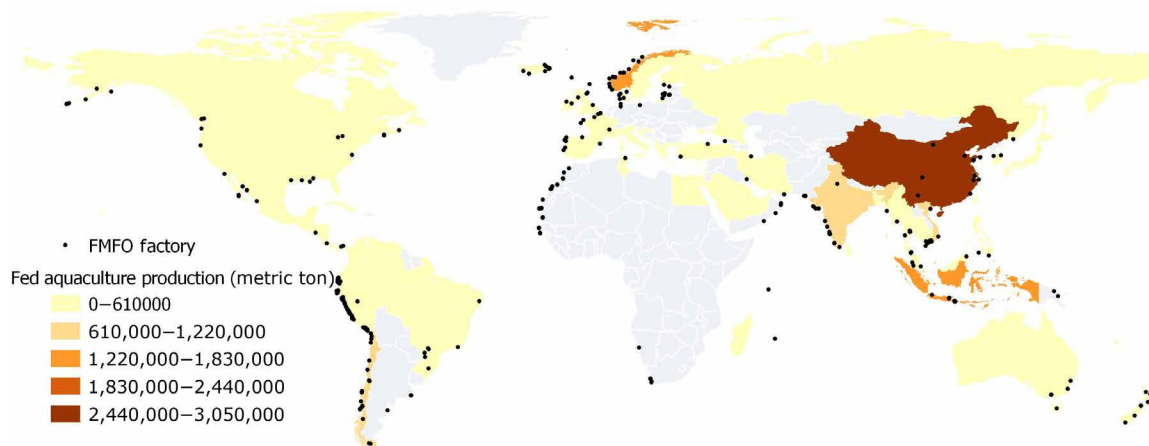


Fig. 6. Global distribution of FMFO factory locations and aquaculture production. Factory locations are indicated by black dots. Country polygons are shaded to represent fed aquaculture production (mt) [data source: Clawson *et al.* (28)]. Darker shades indicate higher production levels. No data were available for countries shaded in grey.

indicating the country of their destination (37). Mauritania, a member of FiTI, is a role model in this regard as the Institut Mauritanien de Recherches Océanographiques et des Pêches (IMROP) publishes a list of approved FMFO production sites in their annual report (38). With improved data transparency in the FMFO industry, we can better understand industry impacts and inform the development of policies to promote more sustainable, responsible, and equitable practices across the supply chain.

Policymakers must consider how factories and the sourcing of fish to support their operations effect community stakeholders, such as local fishers, processors, and consumers as well as the surrounding environment and management of fisheries. This is especially crucial in areas with high factory density, such as coastal towns in Peru. A more comprehensive governance approach will require multiple interconnected elements: (i) cross-sector collaboration, for instance between fisheries management authorities, labor departments, and civil society groups; (ii) effective governance with enforcement mechanisms, including setting and enforcing science-based quotas and robust monitoring systems procedures; (iii) inclusive decision-making processes that meaningfully incorporate local community voices, including fishers and processors, in how marine resources are used and managed; and (iv) clear accountability measures. The Global Roundtable on Marine Ingredients represents a step toward this integration, bringing together industry, NGOs, and other stakeholders to address environmental and social challenges in the FMFO industry (39).

Future research could build on this data by comparing areas where FMFO factories are performing better or worse environmentally, socially, and/or economically. In addition, more research is needed on the waste and emissions created by these factories and ways to reduce their environmental impacts [see (40) for an example].

FMFO are limited resources, and although the use of novel feed ingredients is on the rise (22), they are unlikely to make a major contribution to the industry for years to come. Therefore, it is crucial to support the environmentally sustainable and socially responsible management of the FMFO industry as it stands. Despite concerns regarding the use of whole fish for FMFO production, it remains an effective waste management strategy for fish processing

activities via the use of by-products for FMFO production. Policies should be better designed to incentivize by-product rendering for circular food production systems.

MATERIALS AND METHODS

Our approach was informed by (28) and (41), two studies which investigated the spatial distribution of mariculture farms around the globe. The study covers all countries ($n = 63$) that produced at least 500 tonnes of fish oil in 2022, according to data provided by the International Fishmeal and Fish Oil Organization: Marine Ingredients Organization (herein referred to as “IFFO”). The justification for focusing on these 63 countries is that they produced 99.8% of global fish oil supply in 2022.

FMFO production companies

We compiled the spatial database by first searching for FMFO production companies in each of the selected countries ($n = 63$). Company names were found using national databases and membership associations (e.g., the EFFOP, IFFO, and Marin Trust), peer-reviewed and gray literature, as well as online seafood business directories (e.g., www.trade-seafood.com). The data search was conducted in English, but efforts were made to translate publicly available national reports and company websites using Google Translate. Country-specific data sources can be found in table S1. Data collection took place from February to May 2024.

IFFO is an international trade organization for marine ingredients (including FMFO). IFFO members account for 55% of FMFO production and more than 80% of FMFO traded globally (42). Because this study focuses on production factories, rather than trade, only members listed as “producers” in the “level” column of the IFFO members list were included in the dataset.

MarinTrust is a certification program for marine ingredient production factories that recognizes responsible fishery sourcing and production of marine ingredients (including FMFO) (43). Companies

fall under two international third-party MarinTrust certification standards: the Factory Standard (MarinTrust Standard), covering the “sourcing and production of marine ingredients at the factory”; and the Chain of Custody Standard, which “allows businesses in the supply chain (e.g., processors, packers, storage providers etc....) to be recognized for their use of MarinTrust certified ingredients” (43). MarinTrust also operates an Improver Program “dedicated to marine ingredient production factories involved in a Fishery Improvement Project” (43). All sites that met factory standard or were part of the improver program were included. The open-source certificates for these two categories were highly detailed and included the company name, site address, the species used for raw material as well as whether the raw material was whole fish or by-products from other fish processing activities. Companies/sites that met the Chain of Custody Standard were only included if they were described as “producing” or “processing” FMFO. We did not include sites that only participated in trading, storage, distribution, packing, and/or packaging.

Once a list of FMFO-producing companies was compiled, we searched for company websites to find information regarding the number and location of production plants the company operated. If a company website could not be found, the production company was still included in the table, as long as it was listed as a producer of FM and/or FO by a membership association (e.g., IFFO and EFFOP), a certification program (i.e., MarinTrust), a business and/or producer/supplier directory (e.g., trade-seafood.com), or a business account on a social networking platform (e.g., LinkedIn).

Locating FMFO production factories

Using the data collected above, we attempted to locate each company’s factories and verify their location using the satellite image layer in Google Maps. Verification involved zooming in to the presumed location and checking that there was a factory building there (Fig. 7). Once verified, the coordinates of the plant(s) were recorded.



Fig. 7. Example of factory location verification using the Google Maps satellite layer. All factories had large warehouses and cylindrical tanks for FMFO processing and storage (highlighted in yellow boxes). Factories were typically located on the waterfront and clustered together in industrial zones.

If the company website and/or factory address were not available, then we searched the company name and country in the Google Maps search box to attempt to find the company's factories. In some cases, the factories could not be located due to the absence of a company's website, lack of information on the company's website, or factory addresses that could not be found on Google Maps. When a factory address was provided but could not be pinpointed, we used an open-source geocoding platform (<https://geocode.xyz/>) to geocode the address. This platform also provided a confidence score between 0 and 1 for each geocode result. In instances where the city or province of the factory was provided, we used the geocode for that city or province.

Data types

We categorized the data compiled for FMFO factories into four data types based on our confidence level in each location (Table 1).

Raw materials

We also searched company websites and MarinTrust factory certificates for information regarding raw materials and production capacity for individual factories. We specifically wanted to know if the raw materials being used for FMFO were whole fish or fish by-products. More specific information regarding species and/or functional groups was included when available.

Global FMFO production

Global FMFO production data was provided by IFFO for the year 2022. These data guided our focus on specific countries during our search for FMFO factories and were used to calculate the FM to FO production ratio for each country (Table 2).

FMFO factories and fed aquaculture production

Because fed aquaculture is the largest consumer of FMFO, we included global fed aquaculture production data from (28) in our study. We compared these data with global FMFO production data from the IFFO and factory location data collected in this study to better understand the interactions between these two industries.

Data analysis and visualization

Maps were created using QGIS version 3.4.8. Other data visualizations were made in R studio version 4.3.1.

Supplementary Materials

The PDF file includes:

Table S1
Legend for data S1
References

Other Supplementary Material for this manuscript includes the following:

Data S1

REFERENCES AND NOTES

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