Food and Agriculture Organization of the United Nations

FAO INNOVATION FOR BLUE TRANSFORMATION

Responsible use of fishmeal in aquaculture

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PREPARATION OF DOCUMENT

The authors are Fernanda Garcia Sampaio, Graham Mair, Abdel Fattah M. El-Sayed and Adrienne Egger. Case Study 1 was written by Alberto Nunes, and Case Study 2 by Lena Westlund. The document received input from Manuel Barange, Anders Brudevoll, Lena Westlund, Xinhua Yuan, Stefania Fumo, Xiaowei Zhou, Stefania Vannuccini, Carlos Fuentevilla and Austin Stankus. The document was internally and externally peer reviewed.

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The growth of aquaculture in recent decades has been underpinned by innovations in farming practices, including aquafeed and feeding technologies. Advances in feed formulation, processing, and manufacturing, as well as the use of specific additives (e.g. enzymes and probiotics), have led to improvements in feed conversion ratio.[1] Aquafeed development has become fundamental to the advancement of aquaculture, allowing the best use of raw materials for feed production and optimizing aquaculture efficiency.

[1] Ratio between the dry weight of feed fed and the weight of yield gain.

A critical question regarding the sustainability of aquaculture growth is whether it is driving a corresponding increase in the demand for fishmeal and fish oil as key feed ingredients, thus adding pressure to the associated fisheries. Although fishmeal and fish oil are excellent ingredients for promoting the health and growth of some aquaculture species, factors such as variations in supply and price, competing demands, and negative perceptions of their use are important factors in considering their inclusion rates in aquafeeds.

FAO has always been active in providing guidance on how to adopt sustainable practices in aquaculture, including choosing more sustainable ingredients for aquafeed. To better understand the dynamics of using fishmeal in aquaculture, this document elucidates how the sector has advanced and improved its use based on scientific and technological developments. While this publication provides data on the use of both fishmeal and fish oil, the issues around fishmeal and its nutritional role in aquafeed differ from those relating to fish oil. Thus, the focus of this document is on fishmeal and its use in fed aquaculture.

BOX 1

KEY FACTS AND FIGURES

- The world's consumption of aquatic foods has increased at twice the annual growth rate of population growth since the 1960s, and is predicted to rise further, largely due to aquaculture growth.
- Aquaculture production of aquatic animals has increased from 4.7 million tonnes in 1980 to 94.4 million tonnes in 2022.
- Fishmeal and fish oil are used as ingredients in fed aquaculture. Salmonids and shrimp farming are the main users of fishmeal.
- The proportion of fishmeal used in aquafeeds has declined from 19 percent in 2000 to 9 percent in 2020 (Glencross *et al.*, 2024).
- Fishmeal and fish oil come mainly from the fisheries of small- and medium-sized pelagic species. There is a shift away from the use of wild-caught fish to the use of by-products for fishmeal and fish oil.
- The volume of capture fisheries used for reduction into fishmeal and fish oil has declined from a record 30.1 million tonnes in 1994 to 17.2 million tonnes in 2022.
- The proportion of fishmeal obtained from by-products (e.g. fish trimmings) has increased from 25 percent in 2010 to an estimated 34 percent of global fishmeal production in 2022. This trend is expected to continue in the future.

Source: Authors' own elaboration based on FAO. 2024. *The State of World Fisheries and Aquaculture 2024 – Blue Transformation in action*. Rome. https://doi.org/10.4060/cd0683en and Glencross, B., Ling, X., Gatlin, D., Kaushik, S., Øverland, M., Newton, R., Valente, L.M. 2024. A SWOT Analysis of the Use of Marine, Grain, Terrestrial-Animal and Novel Protein Ingredients in Aquaculture Feeds. *Reviews in Fisheries Science & Aquaculture*, 1–39. https://doi.org/10.1080/23308249.2024.2315049

What is fishmeal and how do we use it?

Fishmeal is made from cooking, drying, and milling fish and fish parts. It can be derived from processing whole fish as well as by-products from fish processing plants (offal and trimmings), derived from either fisheries or aquaculture products. Despite the name, fishmeal can also be made from crustaceans, molluscs, and other aquatic invertebrates.

While fishmeal and fish oil were traditionally sourced from whole wild fish, an increasing percentage is being sourced from fish processing by-products (Figure 1). A growing volume comes from aquaculture products, a trend that is expected to continue in the future, supporting principles of circularity in the future expansion of sustainable aquaculture expansion.

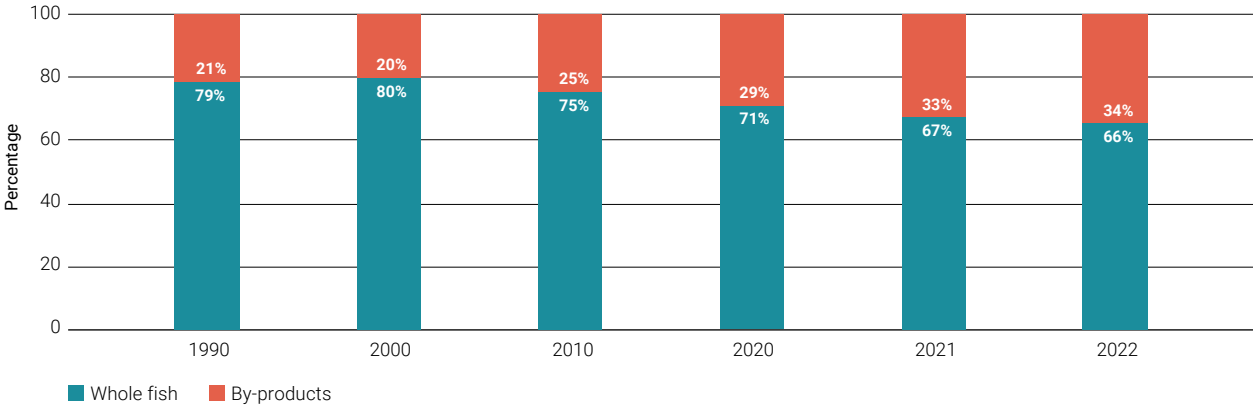
Historically, low-value fish and fish by-products were fed directly to animals (including livestock, chicken, pets, fish and shrimp), either raw or with minimal processing. This traditional practice is decreasing in most (but not all) parts of the world. A range of concerns with this practice drove technological development, allowing low-value fish and fish by-products to be processed and offered in a more stable and safer form as fishmeal.

The development of fishmeal revolutionized the animal feed sector, offering an ingredient with high nutritional value, better product stability and greater utility, thereby creating a commodity with a high market price and demand. Thus, fishmeal started to be utilized as an ingredient in more complex formulated feeds via pelleting or extrusion. Additionally, the palatability of fishmeal allows its use to complement other less palatable commodities, such as soybean and other vegetable meals, increasing the efficiency of their use (Figure 2).

Since the 1990s, FAO has commented on the usage, risks, and benefits of using whole fish, fishmeal, and fish oil as feed inputs in aquafeed, including through documents and guidelines to promote the adoption of more sustainable practices.[2]

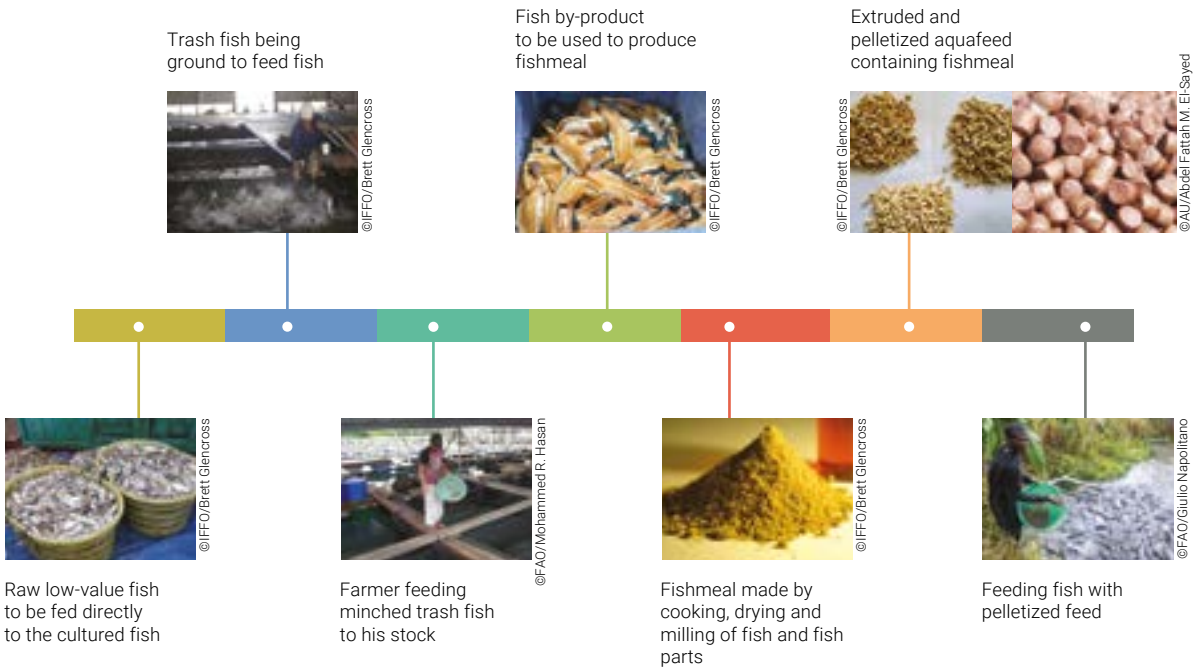
[2] More information about FAO's work in support of the sustainable use of fishmeal can be found in Article 9.1.1 of the Code of Conduct for Responsible Fisheries (CCRF) (FAO, 1995), in the FAO Technical Guidelines for Responsible Fisheries on the "Use of wild fish as feed in aquaculture" (FAO, 2011) and in the 2024 Guidelines for Sustainable Aquaculture (GSA) (FAO, 2024).

Figure 1. Share of fishmeal production from whole fish and by-products, 1990–2022



Source: IFFO. 2024. By-product. https://www.iffo.com/product

Figure 2. The evolution of trash fish/low-value fish use in fed aquaculture



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A fish farmer feeding catfish in Ijebu-Ode, Nigeria.

The role of fishmeal in fed aquaculture

Fishmeal plays an important role in animal nutrition due to its high protein content, essential amino acids, essential fatty acids, digestible energy, minerals, and vitamins, as well as good digestibility and high palatability. For these reasons, almost all global fishmeal production is used in animal feed production.

In 2021, the aquaculture sector was the main consumer of globally produced fishmeal and fish oil (Figure 3) (FAO, 2024). The balance of production is used for livestock, such as pigs and poultry, and other sectors, such as the pet food market. Fishmeal's popularity as an animal feed generates a high market value.

The fed[3] aquaculture sector has been making substantive progress in reducing the amount of fishmeal in aquafeed and improving the diversity of ingredients used, partially as a response to its high price and limited supply.

While aquaculture production of aquatic animals has increased dramatically in recent decades, the volume of capture fisheries utilized for reduction into fishmeal has declined (Figure 4), suggesting that aquaculture growth has not driven an increase in capture fisheries used for reduction into fishmeal.

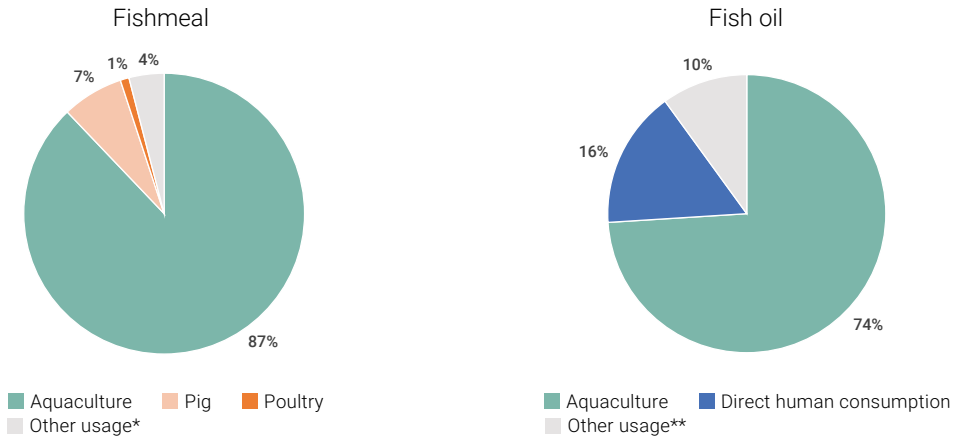
Fishmeal inclusion in aquafeeds varies according to the species produced, the quality, availability, and cost of the ingredient, and the life stage or the cultured species (typically, early life stages require higher levels). However, the exact amount of fishmeal and fish oil used per tonne of feed is difficult to assess as this is often proprietary information. There are different ways to assess the contribution of wild fish in aquafeed, with the fish:in fish out (FI:FO) ratio being one of the more commonly cited. This ratio estimates the amount of wild fish needed to produce 1 kg of aquaculture fish. However, the methodology for its estimation is constantly under review by the scientific community. The literature does, however, contain indicative information about the average amount of fishmeal in feed but does not indicate whether it originates from wild fish or fish processing by-products:

- For shrimp, the proportion of fishmeal in formulated feed has decreased from >25 percent in the 1990s to 12 percent in the past decade (Nunes and Masagounder, 2023), see Case Study 1.
- For salmonids, the average inclusion rate has been reduced from 28.8 percent (Boyd and McNevin, 2022) to 14.0 percent (Naylor *et al*., 2021), over the last 10–15 years.
- Fishmeal inclusion in freshwater fish feeds (especially for tilapia and carp) has been almost eliminated, except for negligible volumes in starter feeds.

[3] Fed aquaculture is defined as aquaculture production that utilizes, or has the potential to utilize, aquafeeds of any type (FAO, 2012).

A farmer disperses feed across the pond from a boat at a shrimp farm at Pudimadaka, Andhra Pradesh, India

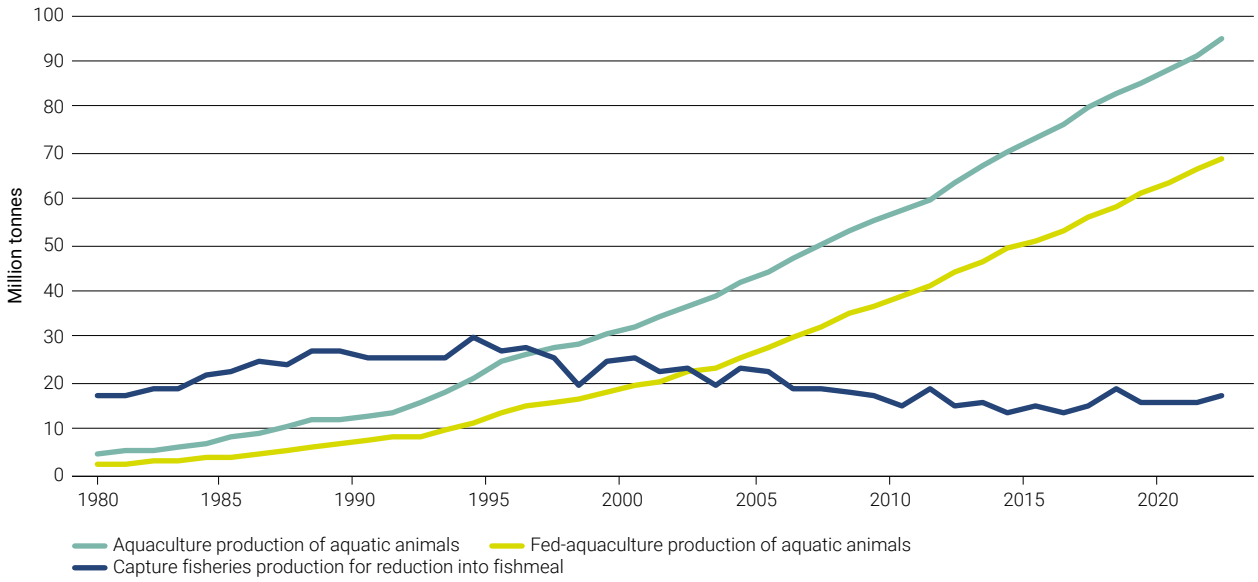
Figure 3. Fishmeal and fish oil utilization, 2021



Note: * Mainly pet food. ** Pet food, biofuel, and cooking oil.

Source: FAO. 2024. *The State of World Fisheries and Aquaculture 2024. Blue Transformation in action*. Rome. https://doi.org/10.4060/cd0683en
Based on IFFO estimates.

Figure 4. Aquaculture and fed-aquaculture production of aquatic animals compared to capture fisheries production for reduction into fishmeal, 1980–2022



Note: Data in million tonnes expressed in live weight equivalent.

Source: FAO. 2024. FishStat: Global production by production source 1950–2022. www.fao.org/fishery/en/statistics/software/fishstatj and FAO. 2024. *The State of World Fisheries and Aquaculture 2024 – Blue Transformation in action*. Rome. https://doi.org/10.4060/cd0683en.

CASE STUDY 1

Efforts of the Ecuador shrimp sector to reduce the amount of fishmeal use

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A. Shrimp *(Litopenaeus vannamei)* produced in Ecuador.
B. Automatic feeder device.

Ecuador is one of the leading global producers of farmed shrimp. Recent advancements in feed technology, including the introduction of extruded sinking feeds* and the shift from manual to mechanical feeding has allowed the shrimp sector to increase productivity and reduce the amount of fishmeal in feed.

Feeds for the grow-out phase are low in fishmeal (<5 percent) with moderate levels of animal by-products (<10 percent) and high in plant proteins. In a grow-out feed, the sum of all plant ingredients may be more than 75 percent, with soybean meal being the most commonly used plant ingredient. This is in line with some studies of feeds for juvenile *Litopenaeus vannamei*. According to some of these studies, soybean meal can replace fishmeal completely, at a stocking density of 35 shrimp/m^2 or less, with or without the use of proteins from terrestrial animals. This reduces the reliance on fishmeal as a dietary nutrient, while functional deficiencies are addressed through supplementation of amino acids, minerals, attractants, and functional feed additives.

While some of the feed ingredients are produced locally, the bulk of ingredients used in shrimp feed is imported, including soybean meal, corn gluten and concentrate, wheat flour, and rendered meat and bone meals, squid meal, krill meal, and soy lecithin.

Additionally, Ecuador has moved from manually feeding shrimp twice a day to 24-hour feeding cycles using mechanical feeders, with associated improvements in growth performance. Ecuador has also adopted acoustic-controlled feeders that automatically determine when, how much and how long to feed by monitoring shrimp feeding activity using a hydrophone placed in the pond. This allows real-time monitoring of feeding responses, together with continuous measurements of dissolved oxygen and temperature. The application of these technologies has been a game changer allowing greater control over feed inputs, reducing waste and labour costs and optimizing shrimp growth rates and feed conversion ratio.

Note: * Several types of processions are used to produce aquafeed, such as pelletized and extruded; generally, extruded aquafeed can float on the water surface or sink along the water column to the bottom of the water body. The type of feed should be made in accordance with the feeding habits of the farmed species.

Source: Authors' own elaboration based on Nunes, A.J.P., Sabry-Neto, H., Silva F.H.P., Oliveira-Neto, A., Masagounder, K. 2019. Multiple feedings enhance the growth performance and feed efficiency of juvenile Litopenaeus vannamei when fed a low-fish meal amino acid-supplemented diet. *Aquaculture International*, 27:337-347. https://doi.org/10.1007/s10499-018-0330-7; Nunes, A.J.P., Dalen, L.L., Leonardi, G., Burri, L. 2022. Developing sustainable, cost-effective and high-performance shrimp feed formulations containing low fish meal levels. *Aquaculture Reports*, 27: 101422. https://doi.org/10.1016/j.aqrep.2022.101422; Reis, J., Hussain, A.S., Weldon, A., Walsh, S., Stites, W., Rhodes, M., Davis, D.A. 2023. Passive acoustic feeders as a tool to assess feed response and growth in shrimp pond production. *Aquaculture International*, 31:1643-1657. https://doi.org/10.1007/s10499-023-01053-3; Roy, L.A., Bordinhon, A., Sookying, D., Davis, D.A., Brown, T.W., Whitiset, G.N. 2009. Demonstration of alternative feeds for the Pacific white shrimp, Litopenaeus vannamei, reared in low salinity waters of west Alabama. *Aquaculture Research*, 40:496-503; Silva, J.F., Hamilton, S., Rocha, J.V., Borie, A., Travassos, P., Soares, R., Peixoto, S. 2019. Acoustic characterization of feeding activity of Litopenaeus vannamei in captivity. *Aquaculture*, 501, 76-81. https://doi.org/10.1016/j.aquaculture.2018.11.013; Sookying, D., Davis, D.A., Soller, D.S.F. 2013. A review of the development and application of soybean-based diets for Pacific white shrimp Litopenaeus vannamei. *Aquaculture Nutrition*, 19:441-448. https://doi.org/10.1111/anu.12050

Innovation supporting the responsible use of fishmeal in fed aquaculture

There are four fundamental strategies to reduce fishmeal use in aquaculture:

i. **Selective use of fishmeal.** Fishmeal has been selectively included in specific stages of aquaculture production. In early-stage development, in the finishing phase of grow-out, and for broodstock, fishmeal inclusion levels are higher, providing higher protein ratios. During the grow-out phase, which is the longest, fishmeal inclusion is lower or completely replaced by other protein sources. This significantly reduces the overall inclusion of fishmeal throughout the full production cycle.

ii. **Improving feed and feeding efficiency**. Commercial feeds and feeding practices have undergone significant technological advances. Feeds offering specific quantities of amino acids and micronutrients with precise formulations improve animal health, survival, and growth rates. According to Glencross *et al*. (2023), over the past 45 years, the typical feed conversion ratio for a variety of aquaculture species has decreased from a range of 1.8–3.0 to a range of 1.2–1.8, demonstrating clear improvements in feed and feeding efficiency.

iii. **Supporting the increase of non-fed and low-input aquaculture.** Producing aquatic food from non-fed and low-input aquaculture results in lower demand for fishmeal and fish oil. Low-trophic species are those that feed lower in the food chain (e.g. omnivores and planktivores). The Guidelines for Sustainable Aquaculture (FAO, 2024) suggest that stakeholders should "promote low-trophic aquaculture species such as filter-feeding finfish, algae/seaweeds, and bivalve molluscs that are properly managed to provide ecosystem services and reduce negative impacts on surrounding ecosystems".

iv. **Identifying alternative ingredients to replace fishmeal.** To reduce fishmeal inclusion, it is necessary to identify potential ingredients that can replace fishmeal without posing major adverse effects on the performance and health of farmed aquatic animals and that are accessible from the point of view of availability and production costs. Rising prices and a limited supply of fishmeal, combined with pressures from public opinion, have forced the aquaculture sector to search for substitute ingredients (see Box 2).

A farmer feeding a pond of tilapia in Abengourou, Eastern Côte d'Ivoire

BOX 2

SELECTING FISHMEAL SUBSTITUTES

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Black Soldier Fly larvae displayed at the Al-Haggag Aquaponics farm in Egypt.

Existing and potential replacements for fishmeal in aquafeed include the following ingredients:

- **Terrestrial animal by-products.** These come mainly from animal processing by-products, including poultry by-products, meat and bone, blood meal, and hydrolyzed feather meal. Challenges for wider adoption include processing quality, which results in poorer digestibility and palatability of some products, and deficiencies in essential amino acids requiring supplementation.
- **Plant-based ingredients.** These come mainly from oilseed by-products, including soybean, cottonseed, rapeseed, sunflower, and sesame seed. They are generally used as meals, cakes, or protein concentrates. Other plant protein sources can include copra, macadamia, cocoa cake, palm kernel, corn, rice, peas, wheat and corn gluten. Soybean meal is currently the most popular substitute for fishmeal due to its availability, reasonable cost, and good nutrient profile. While its use in aquafeed is growing, it represents less than eight percent of all soybeans processed for animal feed use.
  Growth performance obtained from aquafeeds high in plant protein is often inferior to that of fishmeal-based diets mainly due to the presence of antinutritional factors (ANFs) in some plant-based ingredients, limiting nutrient availability. Proper processing of these sources and supplementation with deficient essential amino acids and certain additives (such as proteases and phytases) can improve their quality, thereby increasing their inclusion levels in aquafeeds.
- **Non-conventional protein ingredients**. These include ingredients such as bacteria, biofloc, earthworms, artemia, krill, insects, yeast, macro and microalgae, single-celled proteins and fish silage. Non-conventional protein ingredients need to meet criteria and overcome challenges that can limit their use in aquafeed.
  Most studies on fishmeal substitutes have used a combination of protein sources, highlighting the importance of balanced supplements of essential amino acids, fatty acids, energy, and feed attractants and additives. Adopting a complementary approach between ingredients is a critical strategy moving forward.

Source: Authors' own elaboration based on Egerton, S., Wan, A., Murphy, K., Collins, F., Ahern, G., Surgrue, I., Busca, K., Egan, F., Muller, N., Whooley, J., McGinnity, P., Culloty, S., Ross, R.P., Stanton, C. 2020. Replacing fishmeal with plant protein in Atlantic salmon (Salmo salar) diets by supplementation with fish protein hydrolysate. *Scientific Reports*. 10:4194. https://doi.org/10.1038/s41598-020-60325-7; Fraanje, W., and Garnett, T. 2020. Soy: food, feed, and land use change. (Foodsource: Building Blocks). Food Climate Research Network, University of Oxford; Glencross, B., Ling, X., Gatlin, D., Kaushik, S., Øverland, M., Newton, R., Valente, L.M. 2024. A SWOT Analysis of the Use of Marine, Grain, Terrestrial-Animal and Novel Protein Ingredients in Aquaculture Feeds. *Reviews in Fisheries Science & Aquaculture*, 1-39. https://doi.org/10.1080/23308249.2024.2315049

Limitations to the replacement of fishmeal in fed aquaculture

The following factors should be considered when searching for ingredients to replace fishmeal in fed aquaculture:

- **Nutritional value.** Finding substitute ingredients that match the nutritional profile of fishmeal is a major challenge. Some substitutes may have the desired nutritional profile but lack the easy digestibility of fishmeal and could cause inflammation and compromise animal health. Palatability, which guarantees that animals will be attracted to the feed, improves production efficiency, and avoids feed waste, is also difficult to replicate.
- **Availability and cost.** Ingredients that can replace fishmeal in aquafeed must be affordable and be produced and available in sufficient and reliable volumes to ensure a consistent and adequate supply. Alternative ingredients should not introduce new risks, such as supply chain or biosecurity issues.
- **Environmental impact.** Fishmeal producers must use raw materials from sustainably managed resources, but unsustainable practices have been raised as a concern in some regions (see Case Study 2). In the era of climate change, the carbon footprint of fishmeal production in comparison to their substitutes is important, requiring more data on the life cycle analysis of the different ingredients. Promoting the use of sustainably sourced ingredients in feed formulations and improving feeding management can minimize waste and reduce the environmental impacts of aquaculture.

Members of Buffda and Byfita group feed their caged fish, at Butyaba, Uganda

- **Social impact.** Certification and traceability schemes are increasingly in place to guarantee that raw materials are not coming from species also in demand for human consumption (see Case Study 2). Conversely, fishmeal production could provide employment in some regions, bringing jobs and income.
- **Competition.** The competition for ingredients, for example between direct human consumption and use in the animal feed industry, can cause a shortage of their availability. This can lead to a sharp increase in prices of these ingredients and thus the cost of processed feeds.
- **Climate change.** Climate change poses a serious threat to global food systems, causing uncertainty in the ingredients supply of different land crops for animal feed supply. The potential emergence of new plant and animal pathogens and diseases may aggravate the availability and cost of aquafeed ingredients.

@FAO/Lena Westlund

Small pelagic fish being landed on the beach in Thiès, Senegal

CASE STUDY 2

Socioeconomic impacts of fishmeal and fish oil production in West Africa

West Africa has seen a significant increase in the production of fishmeal and fish oil in recent years. While the industry previously relied on fish processing waste and by-products, as well as on by-catch species, the industry, in contrast to global trends, now also includes wild-caught fish. In Gambia, Mauritania and Senegal, fishmeal is now mainly produced from small pelagic fish species, such as bonga (*Ethmalosa fimbriata*), flat sardinella (*Sardinella maderensis*) and round sardinella (*Sardinella aurita*). This has raised concerns over the impact of this practice on communities dependent on this fish for their livelihoods and nutrition.

The fishmeal and fish oil industry in the region also offers some economic opportunities, including employment along the value chain, inflow of foreign currency and income from taxes, royalties and fishing licenses paid to the governments. However, the social benefits remain limited if they affect the livelihoods, food security and nutrition, and well-being of local communities. There is insufficient data to estimate the net local effects, but country surveys indicate that jobs and livelihoods of postharvest workers, who often are women, are likely affected by this practice in some places. Moreover, it would appear that the contribution of the African fishmeal production to regional aquaculture and livestock sectors remains low as the production is largely exported.

In December 2023, FAO organized a multistakeholder workshop in Ghana to discuss how to optimize food and nutrition security and livelihood benefits of small pelagic species production in West Africa. The workshop concluded that the social-cultural context in the different West African countries should be considered when evaluating the trade-off between fish for human consumption versus fish for animal feed.

The Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (SSF Guidelines) provide important recommendations regarding the need for engaging with small-scale fisheries actors in decision-making relevant to their livelihoods.

Source: Authors' own elaboration based on Corten, A., Braham C-B., Sadegh, A.S. 2017. The development of a fishmeal industry in Mauritania and its impact on the regional stocks of sardinella and other small pelagics in Northwest Africa. Fisheries Research 186: 328-336. https://doi.org/10.1016/j.fishres.2016.10.009; Thiao, D. Leport J., Ndiaye B., Mbaye A. 2018. Need for adaptive solutions to food vulnerability induced by fish scarcity and unaffordability in Senegal. *Aquatic Living Resource*, 31, 25. https://doi.org/10.1051/alr/2018009; Thiao, D. and Bunting, S.W. 2022. *Socio-economic and biological impacts of the fish-based feed industry for sub-Saharan Africa*. FAO Fisheries and Aquaculture Circular No. 1236. Rome, FAO, Worldfish and University of Greenwich, Natural Resources Institute. https://doi.org/10.4060/cb7990en

Trends and future directions

- Aquaculture will continue to grow in the coming decades, reinforcing its role as an important sector of the global economy and a long-term contributor to global food security.
- Evidence suggests that continuing growth in aquaculture production is not necessarily likely to drive increased demand for fishmeal/fish oil
- Current scientific and technological advances have shown that it is possible to produce aquafeed with little or no fishmeal. Research should continue to identify fishmeal replacements and better fishmeal use strategies.
- Advances in processing technologies have allowed high-quality fishmeal and fish oil to be produced from processing by-products derived from aquaculture and capture fisheries and the proportion of such by-products contributing to fishmeal supply will continue to increase.
- Feed formulators, driven by the needs of producers and consumers, must strive to produce feed with available, low-cost ingredients that have low environmental and social impacts and that meet the nutritional requirements of aquaculture species, to ensure a sustainable intensification and expansion of global aquaculture.
- Improving the traceability of fishmeal sources and of all current and potential ingredients in aquafeeds is critical to ensure they also do not compromise the food or nutritional security of consumers.

A fish farmer feeding catfish in Ijebu-Ode, Nigeria.

REFERENCES

Boyd, C.E., and McNevin, A.A. 2002. *Overview of aquaculture feeds: global impacts of ingredient production, manufacturing, and use.* In: D. Allen Davis, ed. Woodhead Publishing Series in Food Science, Technology and Nutrition, Feed and Feeding Practices in Aquaculture. Woodhead Publishing. 3-28 https://doi.org/10.1016/B978-0-12-821598-2.00003-5

FAO. 1995. *Code of Conduct for Responsible Fisheries*. Rome, FAO. https://openknowledge.fao.org/handle/20.500.14283/v9878e

FAO. 2011. *Aquaculture development. 5. Use of wild fish as feed in aquaculture. FAO Technical Guidelines for Responsible Fisheries*. Rome, FAO. https://openknowledge.fao.org/handle/20.500.14283/i1917e

FAO. 2012. *The State of World Fisheries and Aquaculture 2012*. Rome, FAO. https://openknowledge.fao.org/handle/20.500.14283/i1820e

FAO. 2015. *Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication*. Rome, FAO. https://openknowledge.fao.org/handle/20.500.14283/i4356en

FAO. 2024. *The State of World Fisheries and Aquaculture 2024. Blue Transformation in action*. Rome. https://openknowledge.fao.org/handle/20.500.14283/cd0683en

Glencross, B., Fracalossi, D.M., Hua, K., Izquierdo, M., Mai, K., Øverland, M., Robb, D., Roubach, R., Schrama, J., Small, B., Tacon, A., Valente, L.M.P., Viana, M-T., Xie, S. & Yakupityage, A. 2023. Harvesting the benefits of nutritional research to address global challenges in the 21st century. *Journal of the World Aquaculture Society*, 54(2), 343-363. https://doi.org/10.1111/jwas.12948

Naylor, R.L., Hardy, R.W., Buschmann, A.H., Bush, S.R., Caio, L., Klinger, D.H., Little, D.C., Lubchenco, J., Shumway, S.E. & Troell, M. 2021. A 20-year retrospective review of global aquaculture. *Nature*. 591: 551-563. https://doi.org/10.1038/s41586-021-03308-6.

Nunes, A.J.P. & Masagounder, K. 2023. Optimal Levels of Fish Meal and Methionine in Diets for Juvenile Litopenaeus vannamei to Support Maximum Growth Performance with Economic Efficiency. *Animals (Basel)*. 13(1):20. https://doi.org/10.3390/ani13010020

The FAO Innovation for Blue Transformation series introduces relevant policy initiatives, mechanisms and tools available to promote innovation and technical solutions that can accelerate aquatic food systems transformation. The series shares brief and practical knowledge needed for sustainable and resilient aquatic food systems that can nourish the world's growing population, providing solutions to the challenges preventing aquatic food systems from delivering their full potential.

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