European Commission

Study on Feed for Aquaculture – "Aquafeed"

Final Report



2026

EUROPEAN COMMISSION

European Climate, Infrastructure and Environment Executive Agency
Unit D3 Sustainable Blue Economy

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EUROPEAN COMMISSION

Study on Feed for Aquaculture – “Aquafeed”

CINEA/2022/OP/0014 Specific Contract No.2
Implementing
Multiple Framework Contract in cascade for the provision of scientific advice for aquaculture

This report should be cited as:

Mosnier, P, Howard, C., Roussos, E., Triantaphyllidis, G., Kotzamanis, Y., van Eys, J., Kulikowski T., Szulecka O., van den Burg, S., Poelman, M., Hendricksen, J., Bardocz, T., Aranda, M., Arantzamendi, L., Power, A., Pham, N., Cusimano, G., Vella, E., Deguara, S., Hodgson, S., Mytlewski, A., Rakowski, M, N., and Love, A., Cidad, M., San Martín, D., Ramos, S., Wakeford, R.C. (2026), Study on feed for aquaculture - Aquafeeds. Final Report. Publications Office of the European Union, 2026, doi: 10.2926/8461677

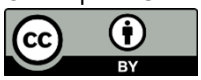
European Climate, Infrastructure and Environment Executive Agency (CINEA)
2026 European Maritime, Fisheries and Aquaculture Fund (EMFAF) EN

Manuscript completed in June 2026

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Luxembourg: Publications Office of the European Union, 2026

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PDF ISBN 978-92-9405-371-8 doi:10.2926/8461677 HZ-01-26-051-EN-N

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List of Abbreviations

Acronym	Definition / Explanation
ANF	Anti Nutritional Factor
Aquafeed	Compound feed produced for aquaculture species
ASC	Aquaculture Stewardship Council
BAP	Best Aquaculture Practices
BM	Blood meal
BSE	Bovine Spongiform Encephalopathy
CFP	Common Fisheries Policy
CINEA	European Climate, Infrastructure and Environment Executive Agency
CO_2-eq	Carbon Dioxide Equivalent
CSRD	Corporate Sustainability Reporting Directive (EU)
CTU	Comparative Toxic Units
DCF	Data Collection Framework (EU)
DHA	Docosahexaenoic acid
DHC	Direct Human Consumption
DMA	Double Materiality Assessment
EC	European Commission
EEA	European Economic Area
EEC	European Economic Community
Economic FCR	Measure of feed efficiency that takes into account total feed used during production and total net fish weight gain
EFSA	European Food Safety Authority
EHA	Eicosapentaenoic Acid
EMFAF	European Maritime, Fisheries and Aquaculture Fund
EPA	Eicosapentaenoic Acid
EU	European Union
FAO	Food and Agriculture Organization
FCR	Feed Conversion Ratio
FEFAC	European Feed Manufacturers’ Federation
FMFO	Fishmeal and Fish Oil
FTE	Full-time Equivalent
GHG	Greenhouse Gas
GMO	Genetically Modified Organism

Acronym	Definition / Explanation
HACCP	Hazard Analysis and Critical Control Points
IAFFD	International Aquaculture Feed and Feed Database
IUU	Illegal, Unreported, and Unregulated fishing
kt	Thousand tonne
kWh	Kilowatt-hour
LCA	Life Cycle Assessment
MSC	Marine Stewardship Council
MSY	Maximum Sustainable Yield
Mt	Million tonne
NPK	Nitrogen, Phosphorus, and Potassium fertiliser
PAP	Processed Animal Protein
PBM	Poultry By-product Meal
PEF	Product Environmental Footprint Category Rule
PEFCR	Product Environmental Footprint Category Rules
PP	Polypropylene
RAS	Recirculating Aquaculture Systems
SBM	Soybean Meal
SCP	Single Cell Protein
SGR	Specific Growth Rates
SSR	Self Sufficiency Rate
t	Tonne
WTO	World Trade Organisation
WOAH	World Organization for Animal Health

Executive Summary

Ensuring a competitive and resilient aquaculture sector, as outlined under the EU’s *Strategic guidelines for aquaculture,* cannot be unlocked without understanding the role of aquafeeds (including feed materials, compound feeds, premixtures and additives), and the factors that influence the market (feed materials are defined as raw inputs and premixes). This study therefore aimed to assess the current state of the aquafeeds for primary farmed and consumed species in the EU across key areas of policy and regulatory frameworks, market trends, traceability and transparency, alternative and emerging materials, and sustainability aspects. To achieve this, a comprehensive literature and data review of scientific articles and pertinent grey literature, as well as consultation with key expert stakeholders across the supply chains, was conducted.

Policy and regulatory aspects

There is no specific EU Aquafeed regulation with the area being covered under various regulations on feed and food, the study first highlights the relative complexity of the policy and regulatory framework for aquafeed, aquafeed materials, and aquafeed additives informed by several different objectives including:

- **A focus on food safety**, in terms of ensuring that aquaculture products are fit for human health, with food safety risks a persistent challenge for the aquafeed sector.
- **Increasing concern regarding environmental impacts**, particularly as regards the sourcing of raw materials of aquafeed (fishmeal and fish oil, but also soy products) as well as the social and economic aspects of its manufacture.
- **Compliance with international trade laws**, given that fish and fish products (including aquafeed), are some of the most globally traded food related commodities. Internationally agreed standards relating to food and feed are directly relevant to the policy and legal framework for aquafeed and the trade obligations of the EU under international law.
- **An increasing number of private or voluntary standards**, which are relevant through ecolabelling and other voluntary certification schemes, often seeking to go beyond the Mandatory standards applicable.

Aquafeed market dynamics

The European aquafeed sector has demonstrated resilient growth over the past five years, with a 2.1% rise in feed production in 2024 continuing that trend**. In 2024, Europe (EU and Non-EU) produced 9.1% (4.8 million tonnes) of the global production of aquafeed** (Alltech, 2025). This has largely been driven

by increases in production of Atlantic salmon, European sea bass and gilthead seabream, with this report also illustrating growth across rainbow trout, meagre, shrimp, sole, sturgeon and Atlantic bluefin tuna (which is often fed non-compound feeds). Compound diets for carp (at an EU level) have not increased significantly, while the feed demand for turbot has remained flat. Production figures of aquafeeds in the EU are limited but **feed demand for the 10 studied species was calculated at almost 1.1 million tonnes in 2023** up from 880,000 tonnes in 2013.

The range of aquafeed materials has expanded enormously in the last few decades, primarily driven by the growing feed demand, as well as in response to greater understanding of material’s biological implications, supply chain pressures, food security objectives, sustainability targets and changing legislation/regulation. Fishmeal and fish oil remain critically important materials in fed aquaculture, though the contribution and importance of plant-based materials (which typically make up around 75% of fed fish diets) are typically underestimated. The basket of available materials for feeds extends to a huge range of materials from marine sources (fish meal, fish oil, krill, macroalgae, and byproducts from the fish processing sector), terrestrial plant sources (soy, wheat, barley, maize in particular) and terrestrial animal products and by-products (processed animal proteins or PAPs).

An evolving market demand driven by considerations of consumer preferences (such as organic production), new scientific developments, (such as GMOs) and new food sources have facilitated the urgence of new suitable materials with various cost, health, growth performance and regulatory considerations (including insects, microbes, microalgae). Furthermore, a range of feed additives (used to enhance technical aspects, feed palatability and improvements in fish health and growth performance) add more complexity to the landscape.

Sustainability, traceability and transparency

With the increased demand for aquafeed and aquafeed material come **continued challenges and opportunities for supply chain sustainability, transparency and traceability**. Of particular attention in the current market is the environmental sustainability of different aquafeeds and their components. In this report, the energy and resource requirements, as well as the CO_2 emissions of different species’ diets were reviewed, unearthing a clear variability in the environmental impact depending on materials used, sourcing, processing, transportation and utilisation efficiency.

To enhance sustainability and transparency 22 key certification schemes and eco-labels were identified as being pertinent to the aquafeeds supply chain, both at a global and EU level.

1. Introduction

1.1. Project background

Aquafeeds (including compound feeds, feed materials (feed materials are defined as raw inputs and premixes) and feed additives) are a crucial component in the continued growth and production of fed farmed species (FAO, 2024a). **Sustainable and secure aquafeed supply chains are imperative to develop a competitive and resilient aquaculture sector** in the EU in line with the *Strategic guidelines for sustainable aquaculture development* (COM (2021) 236 Final) ([1]) and to align with the wider EU Green Deal including the bioeconomy and sustainable blue economy strategies ([2])([3]). Improving the efficiency of natural resource usage (including feed) and minimizing related environmental impacts is also a key target of the FAO’s Blue Transformation Roadmap (FAO, 2022).

Aquafeed supply chains face challenges: **geopolitical conflict** in eastern Europe has impacted commodity prices (Devadoss & Ridley, 2024) and supply chain security (potentially compounded by the **EU’s continued low self-sufficiency rates for aquatic products** ([4]); potential **impacts from climate change** on both the distribution and nutrient content of key reduction fishery stocks (Cheung *et al* 2023); rising **demand from consumers for transparency and traceability** of aquatic food supply chains (Peiró-Signes *et al* 2022); and a complex (and at time contradictory and development limiting) **regulatory landscape**.

([1]) COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030. COM/2021/236 final. Brussels, 12.5.2021

([2]) Bioeconomy: The European way to use our natural resources: action plan 2018. Publications Office of the European Union. [Available at: https://data.europa.eu/doi/10.2777/79401]

([3]) COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS on a new approach for a sustainable blue economy in the EU Transforming the EU's Blue Economy for a Sustainable Future. COM/2021/240 final. Brussels, 17.5.2021

([4]) See FEAP (2024) FEAP call for strategic change in European aquaculture to contribute to EU aquatic food self-sufficiency [Available at: https://feap.info/]

1.2. Project aims

This study had the overarching objective of documenting and analysing the market of aquafeed for primary farmed and consumed species in the EU, across 5 key areas:

1. Policy and regulatory frameworks for aquafeed in the European Union (EU) as well as standards set at the international level (including public, private and voluntary standards).
2. Aquafeed supply chains (domestic and international) including production volumes, import and export trends.
3. Traceability and transparency of aquafeed supply chains
4. Trends in alternative and emerging material markets
5. Sustainability aspects related to the aquafeed supply chains, including environmental and socio-economic impacts.

The primary species of focus in the study included:

- Atlantic bluefin tuna (*Thunnus thynnus*)
- Atlantic salmon (*Salmo salar*)
- Common carp (*Cyprinus carpio*)
- European sea bass (*Dicentrarchus labrax*)
- Gilthead sea bream (*Sparus aurata*)
- Meagre (*Argyrosomus regius*)
- Rainbow trout (*Oncorhynchus mykiss*)
- Shrimp (*Litopenaeus vannamei*)
- Sole (*Solea solea* and *Solea senegalensis*).
- Sturgeon (*Acipenser spp*. and *Huso spp*).
- Turbot (*Scophthalmus maximus*)

1.3. Methodology

1.3.1. General approach

The project followed an overarching methodological framework involving (i) a desk-based literature review of primary, secondary and grey literature, and (ii) targeted stakeholder consultations.

The **literature review** utilised relevant scientific articles retrieved from indexing repositories (Google Scholar, PubMed, Scopus, ResearchGate and Web of Science) to gather relevant published literature. Secondary and grey literature was collected where relevant from sources such as regulatory authority

websites and reports, industry/corporate reports and documents and relevant EU-funded research project outputs ([5]).

Targeted stakeholder consultations involved an online survey ([6]), face-to-face/virtual consultations ([7]) and a stakeholder validation workshop ([8]). A summary of the results is provided in Annex 6.

Literature was compiled and analysed using the Zotero ([9]) reference management software. All data were analysed using Microsoft Excel ([10]) and/or R-Studio Statistical Programming Software ([11]).

A more detailed description of the project methodology is available in Annex 1.

1.3.2. Specific approach

Additional steps were taken specific to particular elements of the project outlined in section 3.2.

1.3.2.1. Policy & regulatory aspects

For the policy and regulatory analysis, this includes a comprehensive review of the regulatory landscape, and in particular an analysis of 8 international legal frameworks and standards and 17 EU-level legal and regulatory instruments. The relevance of these policy and regulatory documents to aquafeeds, aquafeed materials and aquafeed additives, and the impact on the market, are assessed.

([5]) For example, relevant projects like PROTEINSECT, PerfomFISH and AquaIMPACT, and other relevant projects found using the Aquaculture Assistance Mechanism Project database and with a database provided by CINEA (see Annex 3)

([6]) Conducted through the Limesurvey platform [See https://www.limesurvey.org/]

([7]) Held remotely via Microsoft Teams [See: https://www.microsoft.com/en-gb/microsoft-teams/group-chat-software]

([8]) Held remotely via MS Teams webinar and Mentimeter [see: https://www.mentimeter.com/]

([9]) See https://www.zotero.org/

([10]) See https://www.microsoft.com/en-gb/microsoft-365/excel

([11]) See https://posit.co/products/open-source/rstudio/

1.3.2.2. Aquafeed supply chain and market trends

FCR and feed demand

A total feed demand, or indicative feed requirement (needed to produce known volumes of farmed fish) was first calculated for each of the aforementioned species using the species' Feed Conversion Ratio (FCR) i.e. **the ratio of the amount of feed used compared to the amount of animal produced** (Fry *et al* 2018). These FCRs (and the ensuing feed demand) were calculated for two life stages – adult fish and juvenile fish (interpreted as the nursery stages prior to the final 'grow-out' period). The FCRs used for each species are included in Table 1 ([12]). **For adult fish, the economic FCR ([13]) was used**, and combined with known production volumes, a total feed demand was calculated using the following equation:

Total feed demand (tonnes) = total production (tonnes) x eFCR

For juvenile fish, given that the production statistics for juveniles are given in number of individuals, an average mass of juveniles was first calculated using the equation:

Mass of juveniles produced (tonnes) = (average juvenile weight (g) x number of fish) / 1000000 {g/tonnes conversion}

A total juvenile feed demand was calculated using this mass and the known FCR through the equation:

Feed demand (tonnes) = mass of juveniles produced x FCR

([12]) While the methodology provides a practical and repeatable calculation for feed demand, it is subject to two key limitations. Firstly, the calculation does not incorporate mortality rates that may have occurred in the production of a known volume of fish, and therefore the feed demand is considered an underestimate in certain cases considering feed would have been given to fish who ultimately died. Secondly, while the scientific literature provided FCRs, it is understood that these experiments are typically conducted under optimally controlled laboratory settings, which may not reflect real world 'on farm' conditions (this bias was somewhat mitigated by considering key expert insights and grey literature in the FCR calculation). Additional species-specific information is available in Annex 3. All production data were taken from FAO FishStatJ (FAO, 2025c) (for harvest values) and EuroStat (2025) (for juvenile production).

([13]) Economic FCR takes into account all feed fed over a production cycle including uneaten feed (waste) and feed fed to mortalities or escapes therefore providing a more accurate picture of total feed use compared to biological FCR.

Table 1 – Key data used for calculation of species feed demand

Species	Total EU production (tonnes live weight) (2023)	Total global production (tonnes live weight) (2023)	FCR		Average Feed cost (€/per tonne feed)
			Juvenile	*Adult*	
Atlantic bluefin tuna	32,638	37,864	n/a	15.00	252
Atlantic salmon	10,511	2,714,650	1.09	1.29	1,570
Common carp	63,430	4,091,350	4.50	4.50	993
European sea bass	86,546	286,968	2.00	2.00	1,123
Gilthead sea bream	105,924	341,289	2.00	2.00	1,123
Meagre	12,522	52,280	2.00	2.00	1,123
Rainbow trout	170,246	1,105,245	1.13	1.13	1,221
Whiteleg Shrimp	101	7,356,982	1.22	1.22	772
Sole	1,809	2,201	2.00	2.00	1,123
Sturgeon	3,276	178,577	1.30	1.30	1,821
Turbot	12,683	73,423	1.20	1.20	1,813

Material demand

The **demand for aquafeed materials was estimated by factoring the total feed demand of each species with the general composition of the appropriate feed** from a range of manufacturers who report this data: Cargill (2023), Skretting (2023), Biomar (2023) and Irida (2023) in the respective year (feed composition was available for the period 2019-2023). Percentage values were multiplied by the total feed demand of each species – where two or more feed profiles were available and average was taken ([14]).

Producers, markets and import & export Trends

An analysis of fishmeal import and export trends was based on data from EUMOFA (2025) and covered the period 2020-2024 for EU-27 MS. The import data provides information on imports (volume and value) from third countries during this period. It identifies the main countries from which fishmeal is imported. Conversely, the main EU importing countries are also identified. The analysis of the import-export relationship also identifies and includes exports to third countries, in order to determine whether there is a positive or negative

([14]) Feed manufacturers do not publish percentage composition of larval/juvenile diets so volumes of materials could not be estimated for these stages. However, given the small volumes of feed consumed at juvenile stages the quantity of individual materials is negligible – less than one tonne per annum in many instances.

trade balance, i.e. whether EU imports of fishmeal are greater than or less than EU exports of the product. Together with EU production of fishmeal, **data on imports and exports are used to identify self-sufficiency and dependency on external producers**.

Self-sufficiency calculations

Apparent consumption is a proxy for demand and a commonly used metric in food market studies. It can also be used for feeds and materials. It is estimated as the following equation:

(3) Apparent consumption (AC) = production + imports – exports.

For example, consider fishmeal. AC equals the amount of fishmeal retained in the EU market for use as an animal feed material. The **self-sufficiency rate (SSR) assesses the extent to which the EU can supply its own market**, expressed in the following equation:

(4) SSR = regional production/apparent consumption (AC).

The SSR indirectly reflects the **level of dependency on foreign (non-EU) providers**.

Challenges and data limitations

When evaluating the major international trade trends relating to marine protein it is worth highlighting that **EU data on marine protein only relates to fishmeal for animal feed in general** (CN-8 code 2301200 ([15])). This code includes fishmeal derived from fish, shellfish, and trimmings. While there is not sufficient granularity in the data to evaluate identify trade flows for by-products, such as fishmeal made from fish processing waste, estimates can be made. In addition, no data on other by-products, (e.g. fish silage), are available. Note also that **it is not possible to precisely distinguish between the different uses of the fishmeal**, though trade organisations provide estimates (refer to 4.1.3.3).

Similarly, **aquafeed has no Harmonized System (HS) or Combined Nomenclature (CN) code**, which impedes the quantification of its international trade, nor is it recorded in public databases (e.g. Eurostat, EUMOFA). Moreover, whereas feeds of many intensively produced species such as trout use commercially manufactured feeds, many other species – such as carp – primarily use farm-made feed (Islam & Hasan, 2020), and others - namely

([15]) Flours, meals and pellets of fish or of crustaceans, molluscs or other aquatic invertebrates, unfit for human consumption. Data available at EUMOFA website https://eumofa.eu/import-export

bluefin tuna – use ‘trash’ fish and bycatch. Therefore, **grey and published literature was primarily used in evaluating global production of aquafeed**.

1.3.2.3. Traceability & transparency of supply chains

Review of the international voluntary frameworks, EU and national legislation as related to feed traceability

Building on the information collected under the policy and regulatory analysis, an analysis of legislation and policy, specific to understanding traceability, sustainability of material sourcing, feed and food safety, and organic production and labelling was conducted.

Review of the voluntary standards about traceability and authenticity

Over 20 voluntary standards covering traceability and transparency in the aquafeed supply chain were identified and reviewed. The aim was to identify common elements between standards, how the standards complement legal obligations, and areas in which they go above and beyond the legally required practice. Standards were also reviewed for the effectiveness of the mechanisms and how/if they improve competitiveness.

1.3.2.4. Alternative and emerging materials

Material selection and classification

Emerging and alternative materials were selected for analysis based on their current or potential relevance to aquafeed systems. Different **materials were assigned to one of the following broad categories**, and an assessment was conducted at this category level:

- Plant-based proteins and oils
- Terrestrial animal proteins and fats
- Marine products and by-products
- Insect meals and oils
- Single-cell proteins
- Fermentation by-products
- Feed additives (technological, sensory, nutritional, zootechnical)

Nutritional and functional evaluation

The detailed **nutritional profiling was extracted from the IAFFD Database** for each feed material, including:

- Crude protein and lipid content
- Essential amino acid composition (lysine, methionine, threonine)
- Gross energy (MJ/kg)

- Digestibility and anti-nutritional factors (ANFs)
- Moisture, fibre, ash and phosphorus content

Information was tabulated to support cross-comparison of nutritional adequacy and potential for substitution in aquafeeds for different aquatic species (e.g., omnivores vs. carnivores, freshwater vs. marine).

PESTLE description of aquafeed materials in the European context

A PESTLE analysis (Political, Economic, Social, Technological, Legal, Environmental) (a tool widely used in strategic market analysis (Johnson *et al,* 2011)) was conducted to identify factors influencing the market for alternative and emerging materials of aquafeeds to enhance EU self-sufficiency and sustainability in the aquaculture sector. The PESTLE framework was applied at the material category level as described above, and a number of sub-factors were assessed (Table 2).

Table 2 – Relevant sub-factors included under the PESTLE framework in this report

Factor	Sub-factor
Political	Subsidies and fundings; trade policies
Economic	Production cost; price volatility; supply stability; material demand
Social	Consumer perception of seafood fed with alternative materials; industry stakeholder attitudes and acceptance; eco-label, voluntary certification
Technological	Production technologies compatible with existing feed production; technological barriers to commercial adoption; available technical knowledge
Legal and Regulatory	Regulations; feed material register
Environmental	Input requirement; emissions

Species Suitability and Practical Application

The compatibility of each feed material with specific aquaculture species was evaluated, focusing on:

- Tolerance thresholds and inclusion rates
- Digestibility and feed conversion efficiency
- Growth performance and health outcomes
- Pellet quality and palatability

Species-specific tolerances (e.g., salmonids vs. carp) were taken into account, with formulation recommendations based on empirical feeding trial results and expert reviews.

Trade and Market Analysis

Statistical data on production, imports, and exports of key feed materials across global and EU markets were compiled. This included:

- Production volumes and trends (2015–2025)

- Top producing and trading countries (2024-2025)
- Trade flow values and volumes (Euro/tonne)

Where possible these data were specific to use by the aquaculture sector. These data supported the evaluation of material availability, supply risks, and market dependencies, especially for Europe’s aquafeed sector.

Prices for alternative and emerging feed materials

Prices, estimated prices, and market trends have been identified for alternative and emerging feed materials. This was achieved through a literature survey and by consulting specialised market analysis pages, feed websites, FAO and World Bank institutional websites, and others available on the Internet. Prices for traditional products such as fishmeal, fish oil and soy products are widely available. However, prices for other materials are scarce. Please note that specialised market websites usually do not provide price information. Nevertheless, they provide useful quantitative information on market size (sales values) and market growth rates (e.g. CAGR), as well as qualitative information on market trends and factors affecting markets. Due to restricted price availability caused by data restrictions and the novelty of some materials, researchers have used the CAGR provided by specialized websites to estimate data for the years 2020 to 2024. This is a very rough approach, since in this case the CAGR reflects sales growth and not necessarily price growth. However, given the novelty of some of the materials and the current state of technology and production, it is possible that increasing demand would not lead to lower prices in the short term. Therefore, the estimated prices could be useful for comparing trends with those of traditional materials.

1.3.2.5. Sustainability aspects

Resource requirements for aquafeed materials

To assess the resource requirements for aquafeed materials a list of materials was selected from the study on aquafeed composition conducted earlier in the project resulting in a list of the most commonly used aquafeed materials. Peer reviewed papers, in addition to, carboncloud ([16]), and Simapro 9.6 LCA software ([17]) utilizing life cycle inventory databases Agri Footprint 5 (An Paassen *et al*., 2019) and Ecoinvent 3 (Wernet *et al*, 2016) were searched to identify key sustainability factors for each material including:

- Water use (m3/t)
- land requirement (ha/t),

([16]) https://carboncloud.com/carboncloud-platform/

([17]) https://simapro.com/

- Energy consumption (kWh/t),
- Greenhouse gas emissions (t CO_2-eq/t),
- Eutrophication marine (kg N eq/t),
- Ecotoxicity freshwater (CTUe/t)
- Particulate matter (disease inc./t)

Economic allocation ([18]) was used when allocating impacts to products, (which avoids the over application of emissions to waste such as husks or straw).

Comparative analysis of environmental sustainability of different aquafeeds

Data were collected from publicly available reports from major feed companies, figures were standardised and emissions from feed production were assessed. Scope one, two, and three were separated out where possible. The assessment was supported by peer reviewed literature where relevant.

Socioeconomic assessment

The market price for key aquafeed materials for the years 2023 and 2024 were compared using data compiled in the previous part of the study. These were compared alongside total global production where data was available, and the interaction between price and production was described. Employment statistics in the feed sector was analysed and discussed based on the best available public data combined with key expert insights.

Sustainability and certification schemes

Building on the data collected and analysed in the traceability and transparency part of the study, this section also analysed further a number of certification schemes and voluntary standards, with a particular focus on sustainability aspects

([18]) When a given process produces several products, the environmental impacts generated in the process should be allocated to the products. The economic allocation is a method of partitioning the impacts among output products based on their relative economic value. Thus, more valuable products receive larger share of the impact. (i.e. In a milling process producing flour, husks or straw, the flour will receive relative more impact than husks or straw).

2. Policy and regulatory frameworks

From a comprehensive review, this report considers key regulations, rules, frameworks and standards that influence the aquafeed, aquafeed material and aquafeed additive market in the EU, including:

- 8 international legal frameworks and standards (Table 3)
- 17 EU-level legal and regulatory instruments (Table 4) which overlap at different stages of the supply chain (Figure 1).

2.1. International policy frameworks

Under this heading, the term international standards should be understood to mean “inter-governmental” or “inter-state standards”, typically agreed through international organisations. While not always legally binding, these frameworks and standards set the guiding principles for legal rules and regulations, as well as guiding private, voluntary (and typically 3rd party) standards and certifications.

Table 3 – List of international frameworks and standards relevant to aquafeed, aquafeed additive and aquafeed materials

Name of instrument	Summary
Agreement on the Application of Sanitary and Phytosanitary Measures	An agreement under the WTO/IPCC system with the general aim of preventing the use of sanitary and phytosanitary measures as disguised barriers to international trade, and measures can only be imposed on the basis of a risk assessment or on recommendations of international standard, guidelines or standard setting bodies.
Technical Barriers to Trade Agreement	An agreement under the WTO system with the primary objective to ensure that ‘technical regulations and standards do not create unnecessary obstacles to international trade’.
General Agreement on Tariffs and Trade	Legal treaty establishing rules for international trade in goods under the World Trade Organization (WTO) system, to which the EU is a member.
International Plant Protection Convention	The basic purpose of the IPPC is to prevent the spread and introduction of pests of plants and plant products, and to promote appropriate measures for their control.
WOAH’s Aquatic Animal Health Code	The main normative text under the World Organization for Animal Health (WOAH), formerly the *Office International des Epizooties* (OIE), which informs governments of the occurrence and course of animal diseases and of ways to control disease outbreaks, coordinating international scientific research on the surveillance and control of animal diseases and facilitating the harmonization of regulations pertaining to trade in animals and animal products.
Codex Alimentarius	Maintained by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO), the Codex Alimentarius sets international food standards, guidelines and codes of practice. Its primary objectives are to protect consumer health and to ensure fair practices in food trade through the elaboration, harmonization and publication of food standards and other related texts.

Name of instrument	Summary
FAO Code of Conduct for Responsible Fisheries	A voluntary agreement that is addressed to essentially all stakeholders in the fisheries and related sectors, with principles and standards applicable to the conservation, management and development of all fisheries.
FAO Guidelines for Sustainable Aquaculture	A set of voluntary guidelines that provide a framework of best practices, principles and recommendations for the sustainable development of aquaculture, with a chapter discussing specific aspects of sustainable aquafeeds.

The starting point for understanding the role of international standards relating to aquafeed is the legal framework for international trade. These are currently contained in **the rules of the World Trade Organisation (WTO)**, established in 1995 from its predecessor organization the General Agreement on Tariffs and Trade (GATT) ([19]). The EU is a member of WTO, as are Norway and the UK.

A key objective of the WTO is to promote trade flows through the successive reduction and removal of tariffs as well as the reduction of trade barriers and the elimination of discriminatory treatment in international trade. Classical trade theory suggests that increased trade in goods, including aquafeed and other aquaculture inputs, will result in lower production costs. However, at the same time an importing country is also entitled to satisfy itself that such products are safe or meet minimum quality requirements.

Two separate agreements, concluded under the auspices of the WTO recognise that while a country may have legitimate grounds to prevent or control the import of such goods, including aquafeed, such controls should not be used as a disguised method to restrict imports in favour of national producers.

These are the Technical Barriers to Trade Agreement ([20]) (the “TBT Agreement”) and the Sanitary and Phytosanitary Standards Agreement (the “SPS Agreement”) ([21]). The basic objective of the TBT Agreement is to ensure that ‘technical regulations and standards, including packaging, marking and labelling requirements, and procedures for assessment of conformity with technical regulations and standards do not create unnecessary obstacles to international trade’ (recital 2). In brief it prohibits the discrimination between domestic products and foreign products on the basis of technical regulations and standards. It is relevant to trade in aquafeed and seeks to ensure that regulations, standards, testing and certification procedures do not create unnecessary obstacles.

([19]) General Agreement on Tariffs and Trade 15 April 1994, 1867, UNTS 187.

([20]) Technical Barriers to Trade Agreement, 5 April 1994, 1868, *United Nations Treaty Series (UNTS)* 120

([21]) The WTO Agreement on the Application of Sanitary and Phytosanitary Measures, 15 April 1994, 1867, UNTS 493.

The rationale of SPS Agreement is slightly different. It aims to prevent the use of sanitary and phytosanitary measures as disguised barriers to international trade. To this end while the right of WTO members to take sanitary and phytosanitary measures necessary for the protection of human, animal or plant life or health is explicitly recognised, measures that may constrain imports may only be imposed on the basis of: (a) a risk assessment; or (b) on the recommendations of international standards, guidelines or recommendations of standard setting bodies.

When WTO member countries apply these standards, they are likely to be safe from a legal challenge under the WTO disputes resolution procedures. Member countries may in addition impose stricter standards but only in accordance with a risk assessment and a number of other requirements of the SPS Agreement. This explains how the EU, and other jurisdictions with major import markets, can require exporting countries to put in place control systems that provide equivalent guarantees of the safety of the food and feed produce to those applicable within the EU.

As regards aquafeed, the relevant international standard setting bodies are:

a) the Codex Alimentarius Commission established by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization) which sets international food standards, guidelines and codes of practice including a code of practice on good animal feeding.
b) the World Organization for Animal Health (WOAH) which is responsible for the Aquatic Animal Health Code ([22]) chapter 4.9 of which is concerned with the "Control of Pathogenic Elements in Aquatic Animal Feed".
c) International Plant Protection Convention, 1997 ([23]) (the IPPC) seeks to prevent the spread and introduction of pests of plants and plant products and to promote appropriate measures for their control, and which through its Commission on Phytosanitary Measures has adopted a series of International Standards for Phytosanitary Measures.

The **FAO's Code of Conduct for Responsible Fisheries** ([24]) is also relevant to the aquafeed sector, and though not legally binding, provides guidance and best practices within the Technical Guidelines on Aquaculture for the responsible and sustainable use of wild fish for aquafeed (FAO, 2011).

([22]) Available at: https://doc.woah.org/dyn/portal/digidoc.xhtml?statelessToken=zfw_HthxEKlyZL2_bnsYOttSotkzpfqWGlFnKBeBqMY=&actionMethod=dyn%2Fportal%2Fdigidoc.xhtml%3AdownloadAttachment.openStateless

([23]) International Plant Protection Convention (New Revised Text) (With Annex). Rome, 17 November 1997. 2367 *UNTS* A-1963.

([24]) Code of Conduct for Responsible Fisheries (adopted 31 October 1995, Resolution 4/95 FAO Conference.

Similarly, the **FAO’s Guidelines for Responsible Aquaculture** provide a framework of best practices, principles and recommendations for the sustainable development of aquaculture, with a dedicated chapter discussing specific aspects of sustainable aquafeeds – this includes sustainable feed sourcing, processing and manufacturing, use of alternative materials (to wild caught fish), ensuring precision formulations to ensuring biosecurity and the safe use of additives (FAO, 2025a).

A full description of all international standards for aquafeeds is provided in Annex 2.

2.2. EU policy

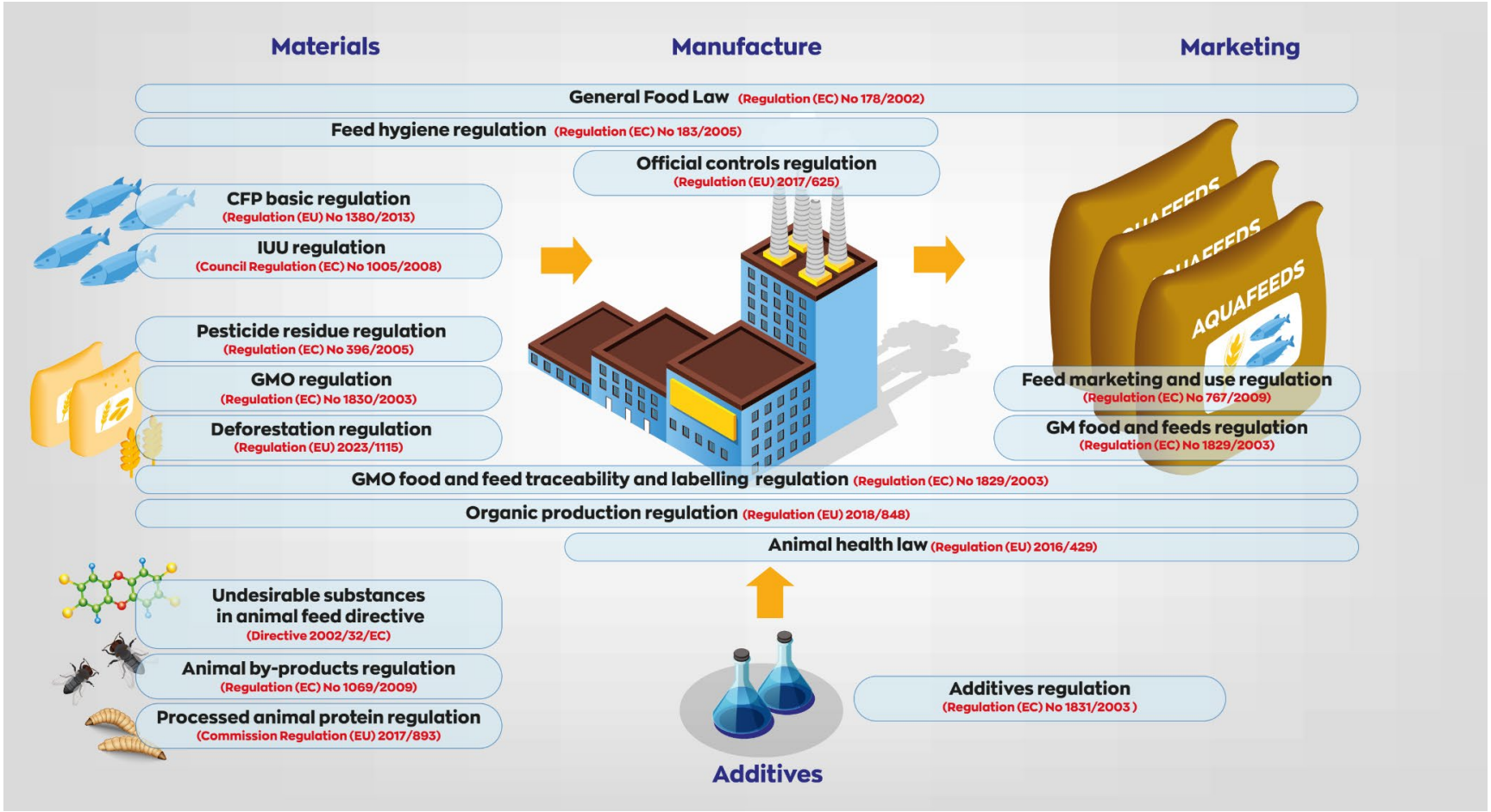
The EU and European policy and legal framework related to aquafeed supply chains extends primarily across three aspects, namely (i) food and feed law, (ii) environmental policy and (iii) fisheries regulations, while international trade agreements and specific rules for ‘third countries’ that trade with the EU also apply. These primary instruments (Table 4) overlap and interact at different stages of the supply chain (Figure 1) with varying impact and relevance to aquafeeds, aquafeed materials or aquafeed additives.

Table 4 – Key legal and regulatory instruments relevant to the aquafeed, aquafeed material and aquafeed supply chain in the EU and Europe

Name of instrument	Summary
Agreement on the European Economic Area (the “EEA Agreement”)	Agreement under the European Free Trade Association that brings Norway (as well as Iceland and Lichenstein) into the EU's internal market, guaranteeing the freedom of movement for goods, services, people and capital, as well as unified related policies.
EU Animal Byproducts Regulation (Regulation No. 1069/2009)	Sets out public health and animal health rules for animal by-products and derived products, in order to prevent and minimise risks to public and animal health arising from those products, and in particular to protect the safety of the food and feed chain
EU Animal Health Law (Regulation No. 2016/429)	The instrument whereby the EU and Member States implement the WOAH Aquatic Animal Health Code and is relevant primarily in the context of the risks to aquatic animal health from pathogens from animal by products contained in aquafeed.
CFP Basic Regulation (Regulation No. 1380/2013)	Sets out a range of management measures to ensure the environmental sustainability of fisheries in EU waters including the establishment of annual fishing opportunities for different fish stocks and the allocation of such opportunities among the Member States for different fish species including species used for fish oil or fish meal.
Deforestation Free Products Regulation (Regulation (EU) 2023/1115)	Provides that products may not be placed on the EU market or exported from the EU if they have been fed with or made from listed commodities including soya beans and palm oil unless they are “deforestation-free” (produced on land that has not been converted from forest use after 2020), produced in accordance with the relevant legislation of the country of production and covered by a due diligence statement.
EU Feed Additives Regulation (Regulation No. 1831/2003)	Creates a procedure for authorising the placing on the market and use of feed additives, including additives used in aquafeeds, and sets out rules for the supervision and labelling of feed additives and premixtures in order to achieve the objectives of the General Food Law.
EU Feed Hygiene Regulation (Regulation No. 183/2005)	Sets out (a) general rules on feed hygiene; (b) conditions and arrangements ensuring traceability of feed; (c) conditions and arrangements for registration and approval of feed manufacturing establishments.
EU Feed Marketing and Use Regulation (Regulation No. 767/2009)	Regulates placing feed on the market in terms of feed content with detailed provisions on information and labelling, feed content, additives, sets out provisions on marketing and labelling provides for the establishment of a Community Catalogue of Feed Materials
EU General Food Law (Regulation No. 178/2002)	Lays down the general principles governing food and feed safety, establishes the European Food Safety Authority (EFSA) and sets out procedures for matters with a direct or indirect impact on food and feed safety.
EU Genetically Modified Food And Feeds Regulation (Regulation No. 1829/2003)	Regulates the authorisation, supervision and labelling of genetically modified (GM) food and feed which can only be used, placed on the market or processed in accordance with the conditions of a formal authorisation that may only be issued it will not, among other matters, have adverse effects on human health, animal health or the environment.

Name of instrument	Summary
EU GMO Food and Feed Traceability and Labelling Regulation (Regulation No. 1839/2003)	Sets out detailed labelling and traceability requirements including as regards systematic recording of information regarding such GM products
EU Invasive Alien Species Regulation (Regulation No. 1143/2014)	Sets out rules to prevent, minimise and mitigate the adverse impact on biodiversity of the introduction and spread within the EU, both intentional and unintentional, of invasive alien species.
EU IUU Regulation (Regulation No. 1005/2008)	Prohibits the import into the EU of fishery products obtained from illegal, unreported and unregulated (IUU) fishing by requiring the import of fishery products into the EU to be accompanied by a catch certificate validated by the flag State of the fishing vessels concerned that certifies they derive from catches have been made in accordance with applicable laws, regulations and international conservation and management measures.
EU Official Controls Regulation (Regulation No. 2017/625)	Lays down rules for the performance of official controls and other official activities by the competent authorities of the Member States to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products which are all relevant to aquafeed.
EU Organic Production and Labelling Regulation (Regulation No. 2018/848)	Establishes the principles and rules for organic production, related certification and the use of indications referring to organic production in labelling and advertising and sets out a number of controls additional to those laid down in the Official controls regulation.
EU Pesticides Residues Regulation (Regulation No. 396/2005)	Specifies maximum levels of pesticide residues in or on food and feed of plant and animal origin by reference to “maximum residue limits” (MRLs) and sets out the procedure for setting MRLs which generally follows the levels set out by the Codex Alimentarius Commission.
EU Processed Animal Protein Regulation (Regulation No. 2017/893)	Amends the Transmissible Spongiform Encephalopathies Regulation to allow the use of various animal products in feed, including aquafeed, including a number of species of insect.
EU Undesirable Substances in Animal Feed Directive (Directive 2002/32/E)	Provides that products intended for use in animal feed may only be imported into the EU or put into circulation if they are free from contaminants (“undesirable substances”) above the maximum levels listed in annex I of the directive.

Figure 1 – Relevance and application of different EU-level legal and regulatory instruments across different stages of the aquafeed supply chain



2.2.1. Food and feed law

The EU policy and regulatory framework for aquafeed, arises from the EU's food safety policy which in turn mainly derives from articles 168 and 169 of the Treaty on the Functioning of the European Union (TFEU) ([25]). Most EU food and food safety legislation is set out in regulations adopted by the European Parliament and the Council, supplemented by subordinate legislation adopted by the European Commission in the form of delegated or implementing acts (hereafter described as "subordinate legislation"). The following are the main instruments relevant to aquafeed:

Regulation No. 178/2002, **the General Food Law** ([26]), which was adopted in 2002, sets out the basic framework and requirements of food law in the EU. It lays down the general principles governing food and feed in general, and food and feed safety in particular, at EU and national level, establishes the European Food Safety Authority (EFSA) and sets out procedures for matters with a direct or indirect impact on food and feed safety. The regulation distinguishes between "food" and "feed". Although not specifically mentioned, **aquafeed is clearly subject to the provisions of Chapter II, "General Food Law"**, which applies to all stages of the production, processing and distribution of food but also to "feed produced for, or fed to, food- producing animals" and among other matters imposes a series of duties on feed all stages of production, processing and distribution including as regards traceability.

The **Undesirable Substances in Animal Feed Directive** ([27]) provides that products intended for use in animal feed may only be imported into the EU or put into circulation within the EU if they are "sound, genuine and of merchantable quality and therefore when correctly used do not represent any danger to human health, animal health or to the environment or could adversely affect livestock production". More concretely, products intended for animal feed are deemed not to be in conformity with this requirement if the level of contaminants they contain, which are described as "undesirable substances", does not comply with the maximum levels laid down in Annex I of the directive.

([25]) Consolidated version of the Treaty on the Functioning of the European Union (OJ C 326, 26.10.2012, p. 4).

([26]) Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety (OJ L 31, 1.2.2002, p. 1).

([27]) Directive 2002/32/EC of the European Parliament and of the Council of 7 May 2002 on undesirable substances in animal feed (OJ L 140, 30.5.2002, p. 10).

Regulation No. 1829/2003, the **Genetically Modified Food and Feeds Regulation** ([28]) regulates the authorisation, supervision and labelling of genetically modified food and feed, with genetically modified (GM) feed defined to mean “feed containing, consisting of or produced from genetically modified organisms (GMOs)”. The placing on the market, use or processing of GM feed is prohibited unless it takes place in accordance with the conditions of an authorisation and such an authorisation may only be issued if GM feed will not, among other matters, have adverse effects on human health, animal health or the environment. This regulation is of relevance to the aquafeed sector in the context of the use in aquafeeds of GM grains and other cereals and indeed a number of GM grain products have been approved for use in feed over recent years (including maize and oilseed rape).

Regulation No. 1839/2003, the **GMO Food and Feed Traceability and Labelling Regulation** ([29]), sets out a framework for the traceability of products consisting of or containing GMOs, and food and feed produced from GMOs, with the objective of facilitating accurate labelling, monitoring the effects on the environment and, where appropriate, on health, and the implementation of the appropriate risk management measures including, if necessary, withdrawal of such products. The regulation sets out relatively detailed labelling and traceability requirements including as regards systematic recording of information regarding such products.

Regulation No. 1831/2003, the **Feed Additives Regulation** ([30]) created a procedure for authorising the placing on the market and use of feed additives, including additives used in aquafeeds, and sets out rules for the supervision and labelling of feed additives and premixtures in order to achieve the objectives of the General Food Law. The term “feed additive” is defined in terms of “substances, micro-organisms or preparations” that are intentionally added to feed in order to achieve one or more of a list of specified functions. A feed additive may only be placed on the market, processed or used in accordance with an authorisation, the specific conditions of that authorisation and relevant labelling requirements.

([28]) Regulation (EC) No 1829/2003 of the European Parliament and of the Council of 22 September 2003 on genetically modified food and feed (OJ L 268, 18.10.2003, p. 1).

([29]) Regulation (EC) No 1830/2003 of the European Parliament and of the Council of 22 September 2003 concerning the traceability and labelling of genetically modified organisms and the traceability of food and feed products produced from genetically modified organisms and amending Directive 2001/18/EC (OJ L 268, 18.10.2003, p. 24).

([30]) Regulation (EC) No 1831/2003 of the European Parliament and of the Council of 22 September 2003 on additives for use in animal nutrition (OJ L 268, 18.10.2003, p. 29).

Regulation No. 183/2005, the **Feed Hygiene Regulation** ([31]) sets out (a) general rules on feed hygiene; (b) conditions and arrangements ensuring traceability of feed; (c) conditions and arrangements for registration and approval of establishments. It applies to the activities of feed business operators at all stages, from and including primary production of feed, up to and including, the placing of feed on the market, the feeding of food-producing animals and feed imports and exports from and to third countries. Feed business operators must ensure that all stages of production, processing and distribution under their control are carried out in accordance with EU legislation, relevant national laws and good practice and must ensure that they satisfy the hygiene requirements laid down in the regulation. Detailed requirements are set out in the annexes to the regulation while operators other than those involved in primary production must put in place, implement and maintain a permanent written procedure or procedures based on the hazard analysis and critical control points (HACCP) as specified by the regulation. In addition, feed business operators must be registered or approved while feed may only be imported from establishments in third countries included on an EU approved list where EU or equivalent hygiene standards apply.

Regulation No. 396/2005, the **Pesticides Residue Regulation** ([32]) specifies maximum levels of pesticide residues in or on food and feed of plant and animal origin by reference to “maximum residue limits” (MRLs) and sets out the procedure for setting MRLs which generally follows the levels set out by the Codex Alimentarius Commission.

Regulation No. 767/2009, the **Feed Marketing and Use Regulation** ([33]) seeks to “harmonise the conditions for the placing on the market and the use of feed” in line with the objectives and principles of the General Food Law by requiring that feed may only be placed on the market and used if it is safe does not have an adverse effect on the environment or animal welfare. To this end it imposes duties on business operators placing feed on the market, including as regards feed content, contains detailed provisions on information and labelling, contains provisions on feed content, including as regards feed additives, sets out provisions on marketing and labelling and among other matters provides for the

([31]) Regulation (EC) No 183/2005 of the European Parliament and of the Council of 12 January 2005 laying down requirements for feed hygiene (OJ L 35, 8.2.2005, p. 1).

([32]) Regulation (EC) No 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC (OJ L 70, 16.3.2005, p. 1).

([33]) Regulation (EC) No 767/2009 of the European Parliament and of the Council of 13 July 2009 on the placing on the market and use of feed, amending European Parliament and Council Regulation (EC) No 1831/2003 and repealing Council Directive 79/373/EEC, Commission Directive 80/511/EEC, Council Directives 82/471/EEC, 83/228/EEC, 93/74/EEC, 93/113/EC and 96/25/EC and Commission Decision 2004/217/EC (OJ L 229, 1.9.2009, p. 1).

establishment of a Community Catalogue of Feed Materials as a tool to improve labelling materials, including compound feed, and to facilitate information exchange.

Regulation No. 1069/2009, the **Animal By-products Regulation** ([34]) sets out public health and animal health rules for animal by-products and derived products, in order to prevent and minimise risks to public and animal health arising from those products, and in particular to protect the safety of the food and feed chain.

The Catalogue of Feed Materials required by the Animal Feed Regulation, is contained as an Annex to Commission Regulation No. 68/2013, the Catalogue of Feed Materials, as amended ([35]).

Regulation No. 1143/2014, the **Invasive Alien Species Regulation** ([36]), sets out rules to prevent, minimise and mitigate the adverse impact on biodiversity of the introduction and spread within the EU, both intentional and unintentional, of invasive alien species, which is potentially relevant in the context of the import and use of non-endemic insect species for use as aquafeed material.

Regulation No. 2016/429, the **Animal Health Law** ([37]), is to implement the commitments and visions provided for in the Animal Health Strategy 2007, including the ‘One health’ principle, and to provide a consolidated, simplified, and flexible regulatory framework. It is also the mechanism whereby the EU and Member States implement the WOAH Aquatic Animal Health Code and is relevant primarily in the context of the risks to aquatic animal health from pathogens from animal by products contained in aquafeed.

Regulation No. 2017/625, the **Official Controls Regulation** ([38]), lays down rules for the performance of official controls and other official activities by the

([34]) Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (OJ L 300, 14.11.2009, p. 1).

([35]) Commission Regulation (EU) No 68/2013 of 16 January 2013 on the Catalogue of feed materials (OJ L 29, 30.1.2013, p. 1).

([36]) Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species (OJ L 317, 4.11.2014, p. 35).

([37]) Regulation (EU) 2016/429 of the European Parliament and of the Council of 9 March 2016 on transmissible animal diseases and amending and repealing certain acts in the area of animal health (‘Animal Health Law’) (OJ L 84, 31.3.2016, p. 1).

([38]) Regulation (EU) 2017/625 of the European Parliament and of the Council of 15 March 2017 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection

competent authorities of the Member States to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products. In other words, many if not all of the instruments that are relevant to aquafeed.

Commission Regulation No. 2017/893, the **Processed Animal Protein Regulation** ([39]), is particularly relevant as regards the use of insects in aquafeed, which amends four annexes of Regulation No. 999/2001, the Transmissible Spongiform Encephalopathies Regulation ([40]) to allow the use of various animal products in feed including aquafeed. The latter regulation, which was adopted following the detection of bovine spongiform encephalitis (BSE), the so-called “mad-cow disease”, as a result of the use of animal by-products from diseased animals in animal feed. The Processed Animal Protein Regulation authorises the feeding of seven insect species to aquaculture animals with a further species added through subordinate legislation in 2021 ([41]).

Regulation No. 2018/848, the **Organic Production and Labelling Regulation** ([42]), establishes the principles and rules for organic production – including organic aquaculture – related certification and the use of indications referring to organic production in labelling and advertising. ‘Organic production’ is defined in article 2 to mean the use of production methods that comply with the regulation at all stages of production, preparation and distribution, including the “conversion period” which is explained in article 10. The regulation also sets out

products, amending Regulations (EC) No 999/2001, (EC) No 396/2005, (EC) No 1069/2009, (EC) No 1107/2009, (EU) No 1151/2012, (EU) No 652/2014, (EU) 2016/429 and (EU) 2016/2031 of the European Parliament and of the Council, Council Regulations (EC) No 1/2005 and (EC) No 1099/2009 and Council Directives 98/58/EC, 1999/74/EC, 2007/43/EC, 2008/119/EC and 2008/120/EC, and repealing Regulations (EC) No 854/2004 and (EC) No 882/2004 of the European Parliament and of the Council, Council Directives 89/608/EEC, 89/662/EEC, 90/425/EEC, 91/496/EEC, 96/23/EC, 96/93/EC and 97/78/EC and Council Decision 92/438/EEC (Official Controls Regulation) (OJ L 95, 7.4.2017, p. 1).

([39]) Commission Regulation (EU) 2017/893 of 24 May 2017 amending Annexes I and IV to Regulation (EC) No 999/2001 of the European Parliament and of the Council and Annexes X, XIV and XV to Commission Regulation (EU) No 142/2011 as regards the provisions on processed animal protein (OJ L 138, 25.5.2017, p. 92).

([40]) Regulation (EC) No 999/2001 of the European Parliament and of the Council of 22 May 2001 laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies (OJ L 147, 31.5.2001, p. 1)

([41]) Commission Regulation (EU) 2021/1925 of 5 November 2021 amending certain Annexes to Regulation (EU) No 142/2011 as regards the requirements for placing on the market of certain insect products and the adaptation of a containment method (OJ L 393, 8.11.2021, p. 4).

([42]) Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007 (OJ L 150, 14.6.2018, p. 1).

a number of controls additional to those laid down in the Official Controls Regulation (Article 1).

A full description of all food and feed related rules, laws and regulations related to aquafeeds is provided in Annex 1.

2.2.2. Environmental policy

In terms of the EU’s environmental policy the main instrument relevant to aquafeed is Regulation (EU) 2023/1115, the **Deforestation Free Product Regulation** ([43]), regulates the placing and making available on the EU market as well as the export from the EU of products listed in Annex I that contain, have been fed with or have been made using relevant commodities. Among these commodities are soya beans (and other soya products) and palm oil both of which are often used in aquafeed. In outlie such commodities must not be placed, or made available, on the EU market or exported from the EU, unless they are “deforestation-free” (in other words produced on land that has not been converted from forest use after 2020), produced in accordance with the relevant legislation of the country of production and covered by a due diligence statement.

A full description of this regulation is provided in Annex 2.

2.2.3. Fisheries regulations (Common Fisheries Policy)

The Common Fisheries Policy (CFP) is primarily relevant to aquafeed in terms of the sustainable use of fish and fish products in aquafeed production. Regulation No. 1380/2013, the **CFP Basic Regulation** ([44]), sets out a range of management measures including the establishment of annual fishing opportunities for different fish stocks and the allocation of such opportunities

([43]) Regulation (EU) 2023/1115 of the European Parliament and of the Council of 31 May 2023 on the making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010 (OJ L 150, 9.6.2023, p. 2060)

([44]) Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC (*OJ L 354, 28.12.2013, p. 22).*

among the Member States for different fish species ([45]). These include a number of fish species used for fish oil or fish meal.

As regards the sustainability of fish and fishery products used in aquafeed that are sourced from outside the EU, Regulation No. 1005/2008, **the IUU Regulation** ([46]), in addressing the issue of illegal, unreported and unregulated (IUU) fishing, prohibits the import into the EU of fishery products obtained from IUU fishing. To this end, fishery products may only be imported into the EU when accompanied by a catch certificate validated by the flag State of the fishing vessels concerned that certifies that such catches have been made in accordance with applicable laws, regulations and international conservation and management measures.

However, particularly as regards fishing in waters under coastal jurisdiction; to be effective, such a system requires the coastal state concerned to adopt, implement and enforce appropriate conservation and management measures in line with the FAO Code of Conduct for Sustainable Fisheries, described above. In particular, the European Parliament has noted that a large proportion of fishmeal and fish oil is caught in the exclusive economic zones of developing countries and expressed particular concern about the unsustainable production ([47]). A full description of fisheries regulations relevant to aquafeeds is provided in Annex 2.

2.1. Rules and regulations related to Norway and UK

Although neither Norway nor the UK are EU members, the policy and legal framework for aquafeed in both countries is extremely close, if not identical, to that of the EU.

In the case of Norway this is due to its membership in the European Free Trade Association (EFTA) and therefore party to the **Agreement on the European**

([45]) Council Regulation (EU) 2025/202 of 30 January 202 fixing for 2025 and 2026 the fishing opportunities for certain fish stocks, applicable in Union waters and, for Union fishing vessels, in certain non-Union waters, and amending Regulation (EU) 2024/257 as regards fishing opportunities for 2025 (OJ L 204, 31.1.2025, p. 1).

([46]) Council Regulation (EC) No 1005/2008 of 29 September 2008 establishing a community system to prevent, deter and eliminate illegal, unreported and unregulated fishing, amending Regulations (EEC) No 2847/93, (EC) No 1936/2001 and (EC) No 601/2004 and repealing Regulations (EC) No 1093/94 and (EC) No 1447/1999 (OJ L 286, 29.10.2008, p. 1).

([47]) Resolution of the European Parliament of 4 October 2022, “Striving for a sustainable and competitive EU aquaculture: the way forward”

Economic Area (the "EEA Agreement") ([48]) (and subject to the same single market rules as EU members Consequently, in accordance with article 7 the EEA Agreement, an act corresponding to an EU regulation becomes part of the internal legal order of an EFTA member in the same manner that a regulation is binding in its entirety and directly applicable in an EU Member State in accordance with article 288 TFEU. As seen above, the vast majority of the legal instruments of the EU policy and legal framework for aquafeed are in the form of regulations. Those **regulations that relate to food and feed law are automatically part of Norway's legal order**, with specifically Norwegian legislation only necessary to enable the implementation of those regulations by identifying the relevant competent authority and to set out sanctions for non-compliance, just as is required by EU Member States. While media reports suggest that the Norwegian Government is proposing that 25% of aquaculture food should be national sourced, this has yet to be legislated for.

In the case of the UK, the reason why the aquafeed legal framework is aligned with that of the EU arises from the manner in which the withdrawal of the UK from the EU took place. On the withdrawal of the UK, the European Union (Withdrawal) Act 2018 provided that from 1 January 2021 certain directly applicable items of EU legislation, including the **regulations relating to aquafeed described in this report, would be converted into UK law**, with the exception of Northern Ireland which remains in the single market and therefore subject to EU legislation.

Now that the UK is no longer a member of the EU, there is clearly potential for aquafeed standards to diverge from those applicable in the EU (with the exception of Northern Ireland). So far this does not appear to have happened. However, what has most definitely happened is that in terms of EU law, the UK is classified as a third country meaning that imports of aquafeed into the EU are now subject to the provisions on third country.

Additional information can be found in Annex 2.

2.2. Impact of policy and regulatory frameworks on the EU feed sector

The previous sections of this report illustrate how the aquafeed market in the EU is subject to a range of different instruments adopted under EU law mostly in the form of regulations (supplemented as necessary and appropriate with

([48]) AGREEMENT ON THE EUROPEAN ECONOMIC AREA (OJ No L 1, 3.1.1994, p. 3; and EFTA States' official gazettes)[Available at: https://www.efta.int/about-efta/legal-documents/eea-legal-texts]

subordinate legislation), while a number of voluntary private standards and certification tools have also been adopted by the industry.

The impact of these instruments on market dynamics and sustainability is contextual and often based at the material level, though at a general level, results from key stakeholders indicate uncertainty (Figure 2). **A number of legal grey areas and contradictions were also highlighted by stakeholders** (Figure 3) including the use of genetically modified organisms in fermentation to produce feeds and high costs for compliance with EU organic rules.

The basic requirements for aquafeed are set out in the General Food Law, the Feed Hygiene Regulation and the Feed Marketing and Use Regulation. Among the responsibilities of EFSA, which was established under the General Food Law, are the authorization of the use of feed additives (under the Feed Additives Regulation) and products of animal origin (under the Animal By-products Regulation) which are subject to a formal approval procedure. These three regulations were considered by surveyed stakeholders to be the most facilitative of market access for and distribution of products in the aquafeed supply chain (Figure 4).

Figure 2 – Stakeholder survey responses to the question: Is the regulatory framework for aquafeeds (i.e. the main policies, laws, regulations and standards that govern the importation, placing on the market, storage, traceability and use of aquafeeds, aquafeed material and aquafeed additives) clear and easy to access, understand and apply? (n=80)

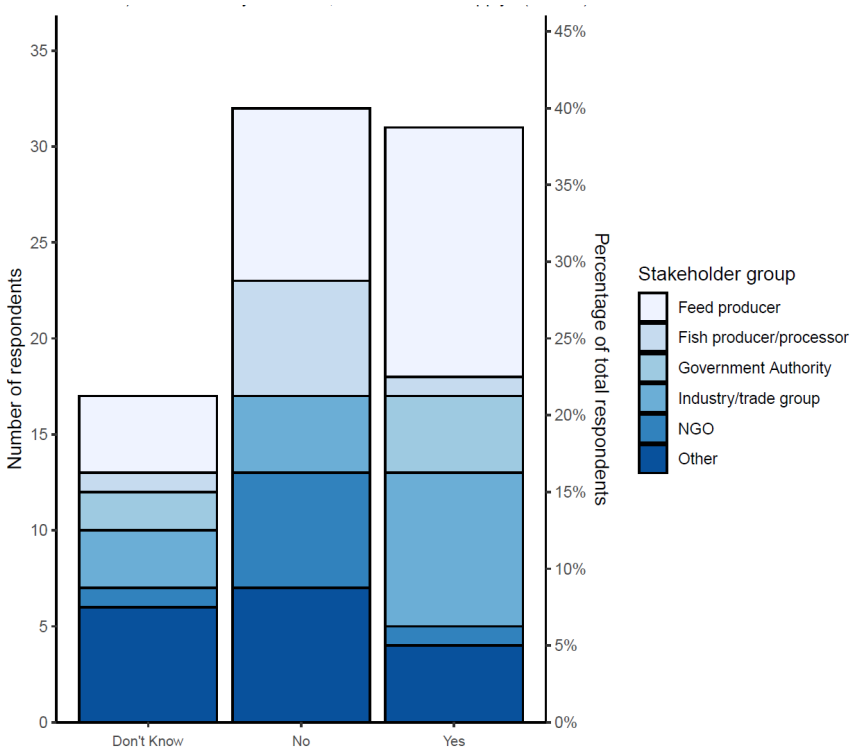


Figure 3 – Stakeholder survey responses to the question: Are there any contradictions, loopholes, gaps, grey areas or other problems with the regulatory framework for aquafeeds that hinder your activities? (n=78)

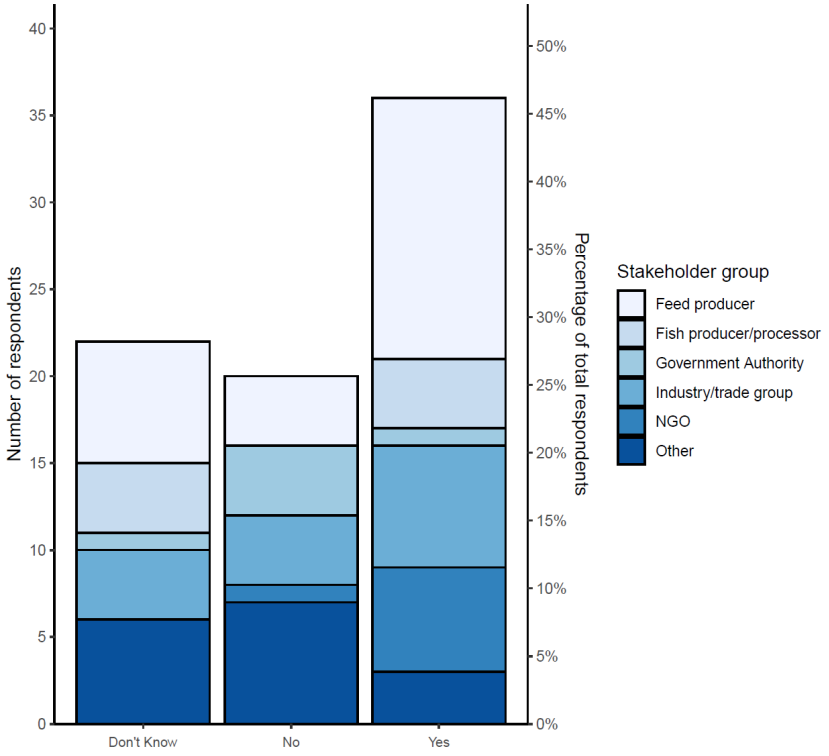
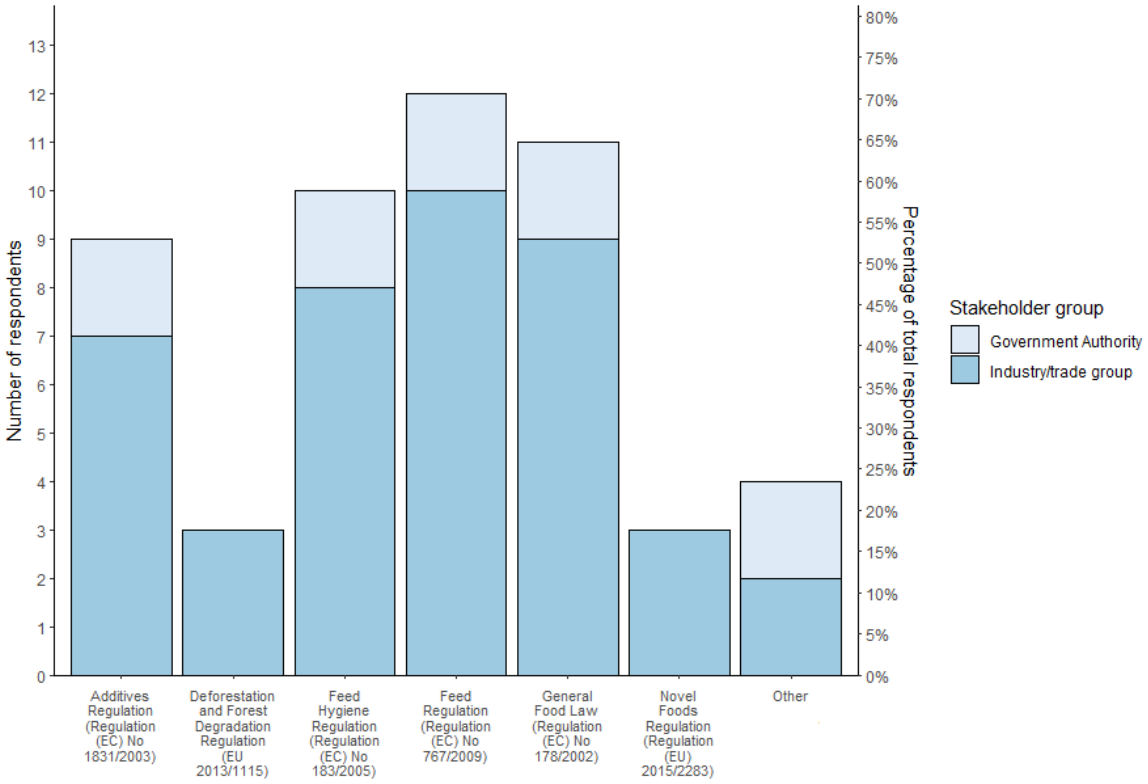


Figure 4 – Stakeholder survey responses to the question: Which EU policy/regulatory documents have facilitated market access and product distribution? (n=17)

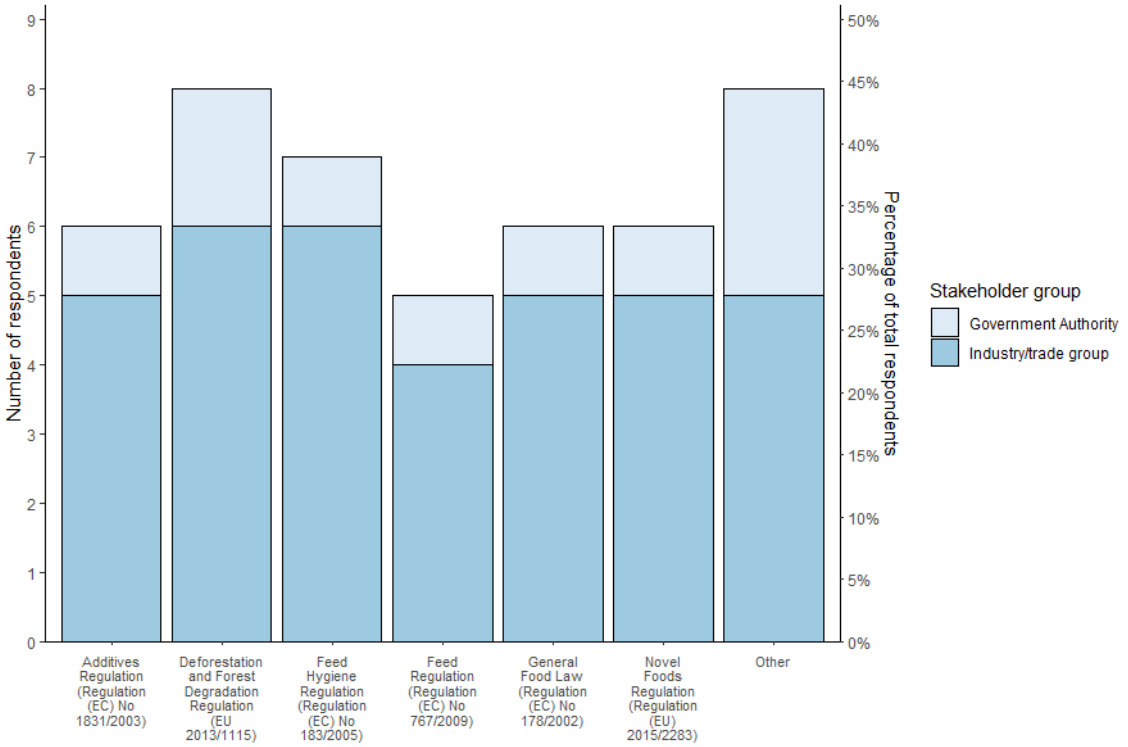


A range of different instruments regulate the quality and other specific aspects of aquafeed materials including the Undesirable Substances in Animal Feed Directive and the Pesticides Regulation. In addition, specific rules apply where:

(a) GM materials are used in aquafeed, under the Genetically Modified Food and Feeds Regulation and the GMO Food and Feed Traceability and Labelling Regulation
(b) Certain types of animal by-product are used in aquafeed under the Processed Animal Protein Regulation
(c) In the case of organic production, the Organic Production and Labelling Regulation

Oversight of the regulatory framework for aquafeed is the responsibility of the competent authorities of the Member States in accordance with the Official Controls Regulation. At the same time, aspects of the sustainability of feed materials in aquafeed are addressed under the Deforestation Free Products Regulation, which is particularly relevant regarding the use of soya products and palm oil, and the CFP Basic Regulation and the IUU Regulation as regards the use of fishmeal and fish oil. But the CFP Basic Regulation, which sets out the EU mandate as regards aquaculture, is silent as regards aquafeed and its use and manufacture beyond the raw marine materials. Surveyed **stakeholders considered several key policy and regulatory documents to have a prohibitive impact on market access and distribution** (Figure 5). In particular, the Deforestation Free Products Regulation was considered as having disproportionate traceability requirements, while the Animal By-Products Regulation and the TSE Regulation were also mentioned by stakeholders as limiting the development and use of animal by-products for aquafeeds.

Figure 5 – Stakeholder survey responses the question: Which EU policy/regulatory documents do you believe have a prohibitory impact on market access and distribution? (n=18)



This is because **the regulatory framework is informed primarily from the perspective of food and feed safety**. It is based on: (i) the core objective of ensuring a high level of protection of human health and consumers' interest (as required by the Animal Health Law); and (ii) and the basic requirement that animal feed, including aquafeed, may only be placed on the market and used if it is safe, of genuine and fit for purpose, of merchantable quality, and does not have an adverse effect on the environment or animal welfare (as required by Feed Marketing and Use Regulation).

EU feed standards are stricter than international standards set by international standard setting bodies, as well as the aquafeed standards of many third (non-EU) countries, with the exception of Norway and the UK. **Stricter standards generally imply higher costs to producers.** On the one hand this means that EU aquafeed producers likely face higher costs in terms of placing aquafeed products on their domestic market than do those in most third countries. At the same time, though, third country aquafeed producers who wish to enter the EU market will face the same costs of complying with EU legislation. And of course, this issue is not confined to aquafeed but applies to all types of animal feed production and marketing. Moreover, as the example of BSE and other food safety crises show, lower food and feed quality standards may result in reduced costs in the short term but prove far more costly to society and the food and feed sector in the long term. At the same time, the current regulatory framework

provides that imported aquaculture products must meet equivalent feed safety standards to those applicable in the EU with imports being Articles 18 and 19 of Regulation 183/2002.

As regards feed additives, the findings of the recent evaluation described above apply equally to the aquafeed sector including as regards reducing administrative and regulatory burden generated of the authorization process. The approval, on the advice of EFSA, of different additives is a complex scientific process and there are clear challenges in terms of evaluating safety and efficiency in the context of aquaculture, which clearly has a number of differences to agriculture. Certain aquafeed additives, including the anti-oxidant ethoxyquin are not approved for use in the EU due to safety concerns.

As regards the issue of sustainability, the Deforestation Free Product Regulation and the relevant fisheries regulations (the CFP Basic Regulation and the IUU Regulation), both seek to promote environmental sustainability of key protein sources for aquafeed. However, perhaps in part as a result, **there is a growing shortage of fishmeal and fish oil** while the aquafeed sector must compete on the global market for heavily in demand palm oil and soya products. For the economic sustainability of the aquafeed sector in Europe, let alone achievement of growth objectives, it is clear that **new protein sources for aquafeed must be developed**. However, the development of these feed sources faces several regulatory challenges.

2.3. Summary

The European aquafeed sector is governed by a comprehensive and stringent regulatory framework. The EU’s core relevant regulations address issues such as food and feed safety, hygiene, marketing, additives, genetically modified organisms, animal by-products, and traceability, alongside environmental and fisheries policies such as the Deforestation-Free Products Regulation and the Common Fisheries Policy. Collectively, these measures aim to ensure high standards of consumer protection, animal health, and environmental responsibility throughout the aquafeed supply chain. However, their complexity and overlapping requirements impose compliance costs and administrative burdens, particularly for operators introducing novel feed materials or additives. Stakeholder feedback highlights persistent legal ambiguities, contradictions, and sustainability challenges, including disproportionate traceability obligations and barriers to the use of animal by-products and innovative protein sources.

While Norway and the United Kingdom maintain near-identical frameworks through the EEA Agreement and retained EU law, the EU’s standards remain stricter than those of most international jurisdictions, increasing production costs but safeguarding market integrity and food safety. In this context, harmonization of certification schemes, regulatory streamlining, and support for innovation are

essential to maintain competitiveness and enable the transition toward sustainable aquafeed systems that align with the EU Green Deal and strategic aquaculture objectives.

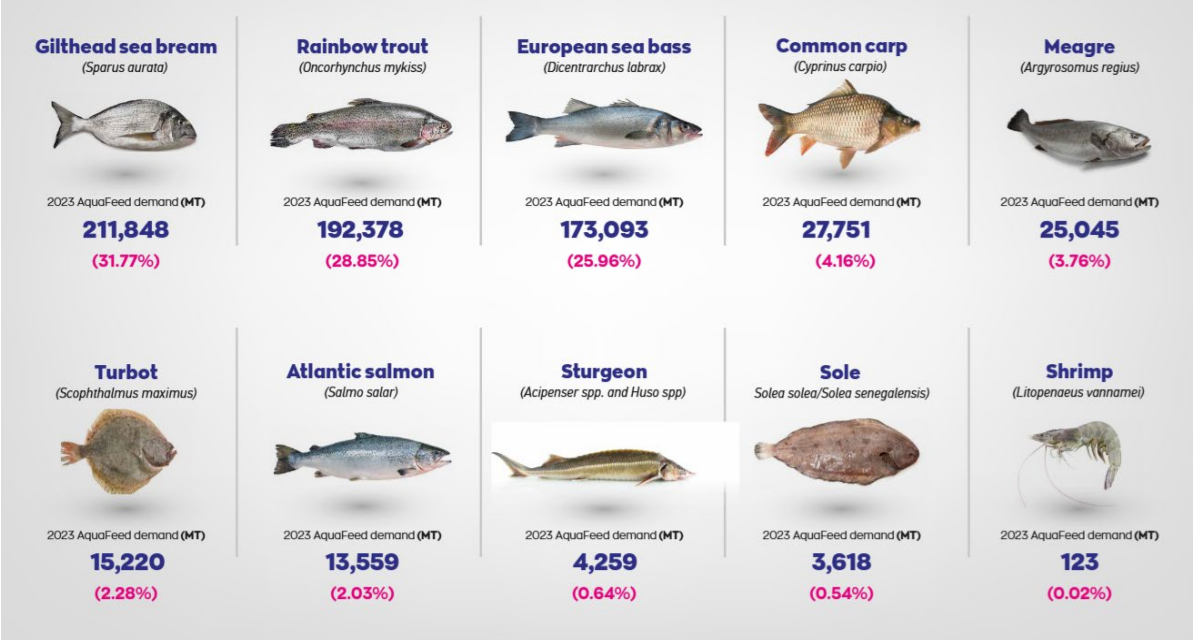
At a global level, frameworks such as the WTO’s Sanitary and Phytosanitary (SPS) and Technical Barriers to Trade (TBT) Agreements, the Codex Alimentarius, the WOAH Aquatic Animal Health Code, and FAO guidelines establish principles for safety, trade fairness, and sustainability.

3. Current state of the EU demand for aquafeed, aquafeed materials and aquafeed additives

3.1. Aquafeed demand and market trend per species in the EU

Aquafeed demand over time was modelled for key aquaculture species for the EU. As production volumes have increased so has feed demand with feed demand in the 10 species investigated increasing from under 900,000 tonnes in 2013 to almost 1.1 million tonnes in 2023, demand for pelleted feeds has risen from 567,058 to 666,893 tonnes. The highest demand for pelleted feeds in 2023 came from Gilthead seabream (31.8% of demand) followed by rainbow trout (28.9%) and European seabass (26%) with the lowest demand of the species studied coming from shrimp and sole (0.02% and 0.54% of demand respectively) (Figure 6).

Figure 6 - EU Pelleted Feed demand (metric tonne) of the ten most important finfish species (2023)



3.1.1. Atlantic bluefin tuna (*Thunnus thynnus*).

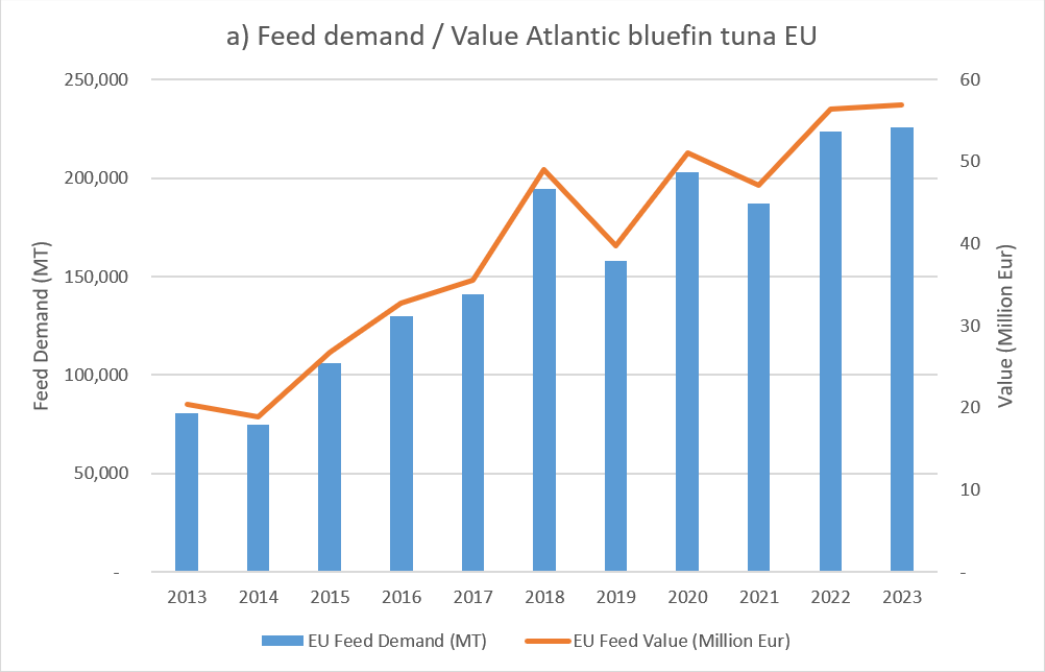
Diets of Atlantic Bluefin tuna typically consist of fresh or previously frozen fishery products, such as anchovy, bogue, cephalopods, herring, mackerel, pilchard, sardine and sardinella (Bridges *et al* 2021; ICCAT, 2021). The exact species fed to the tuna will depend on the availability and price. The

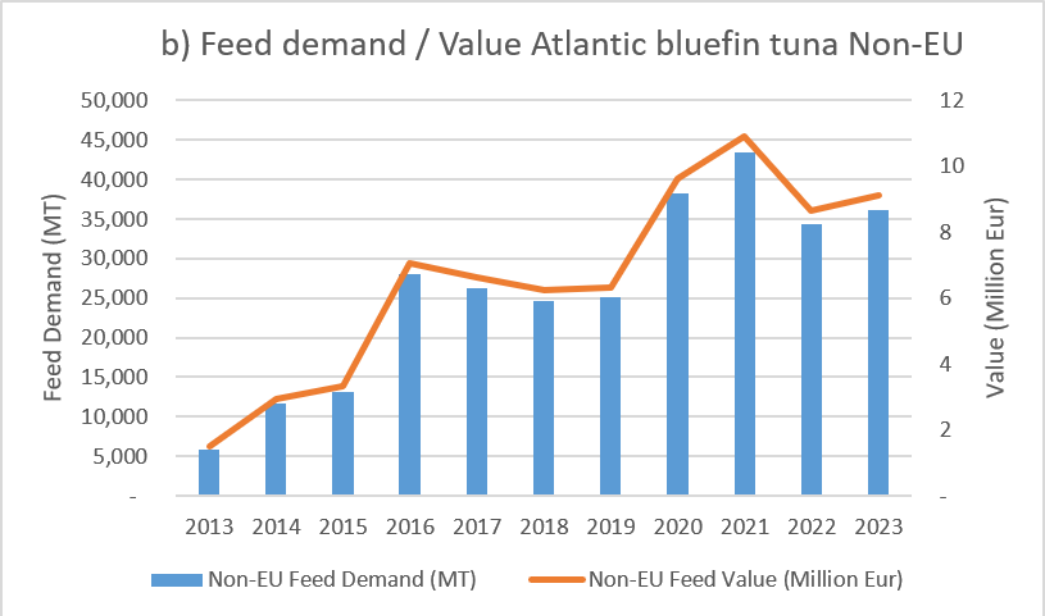
duration of feeding also depends on when the fish were caught and transferred to the farm, the size of the fish and the production plans of the particular farm. New products in the form of soft extruded feed/sausage shaped pellets have been developed for the Japanese Pacific bluefin tuna industry (Skretting, n.d., Buhler, n.d.), but it is unclear what the commercial uptake is in the Atlantic bluefin tuna industry.

Based on the production volumes of Atlantic bluefin tuna, an average weight gain of 46.1% of the total harvested biomass ([49]), and an FCR =15, **feed demand volume can be seen to rise considerably over the last decade** from just under 81,000 tonnes in 2013 to just over 225,000 tonnes in 2023 in the EU, with the corresponding value of the feed used rising from EUR 20.4 million to €56.9 million, nearly a three-fold increase. Figure 7 and 6b below illustrates the trends in feed demand in the EU and non-EU countries respectively between 2013 and 2023, where the EU feed demand was consistently over 80% of global feed demand for this species (varying from 93% in 2013 and 81% in 2021). Non-EU feed demand for this species has increased from 5,900 tonnes in 2013 to 36,000 tonnes in 2023.

([49]) Average increase in weight from purchase of wild in puts to harvest as a percentage of harvested biomass. Data from Malta 2013-2023.

Figure 7 – Feed demand volume/value of Atlantic Bluefin tuna (2013-2023) in the a) EU, b) Non-EU





3.1.2. Atlantic salmon (*Salmo salar*)

Feed demand of adult and juvenile salmon in 2023 was calculated as 3,501,898 and 874 tonnes globally (13,559 and 41 tonnes, respectively, for the EU) (refer to Table 31 for production data). The global value of this feed is estimated at EUR 5.5 billion and EUR 1.4 million for adult and juvenile feed respectively in 2023. However, clearly, the **EU contribution to this figure is very low** indeed, being only 0.4 and 4.4% in volume respectively (Figure 8) (Figure 9).

Figure 8 – Feed demand volume/value for Atlantic salmon (adult stage) (2013-2023) in a) the EU and b) Non-EU

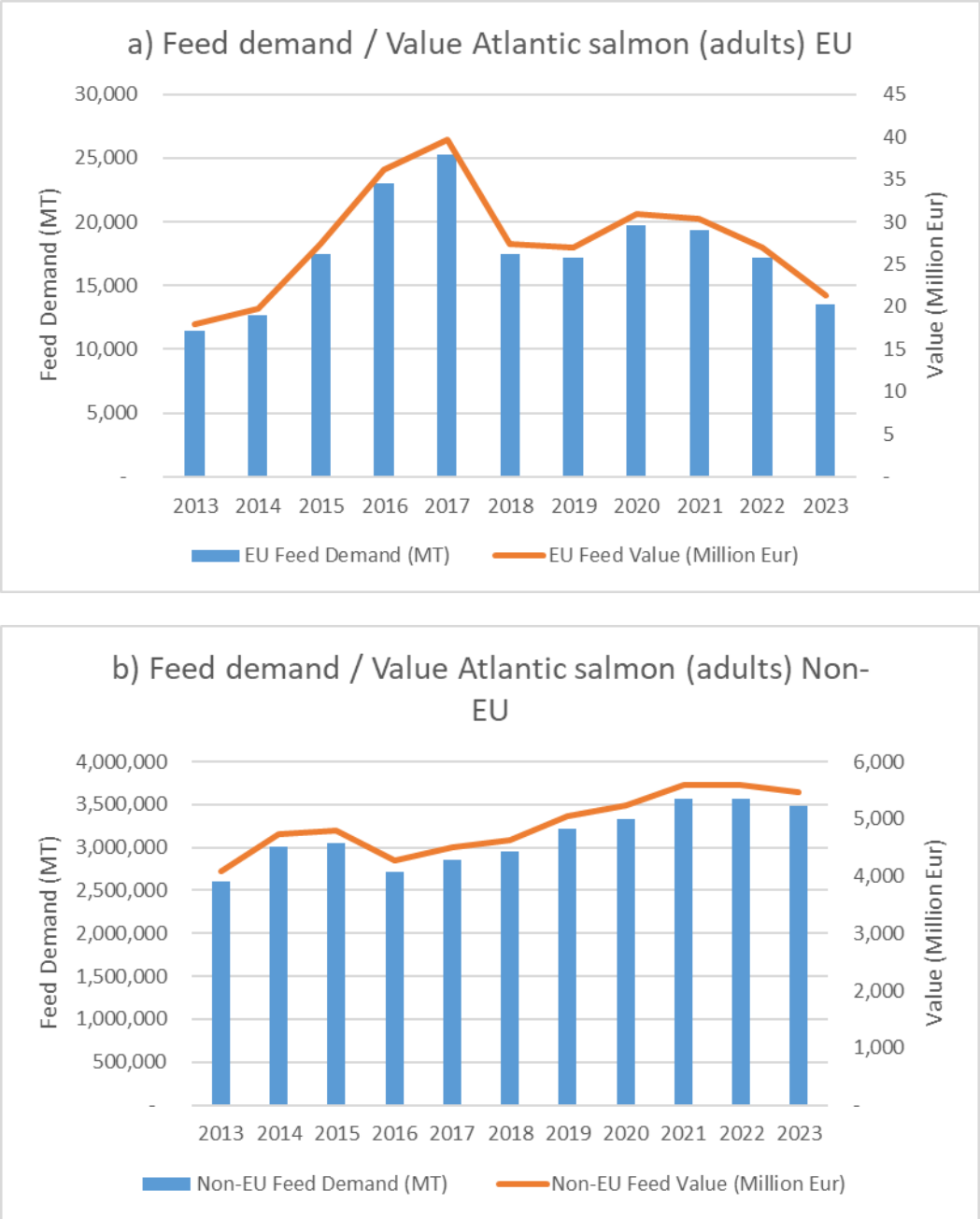
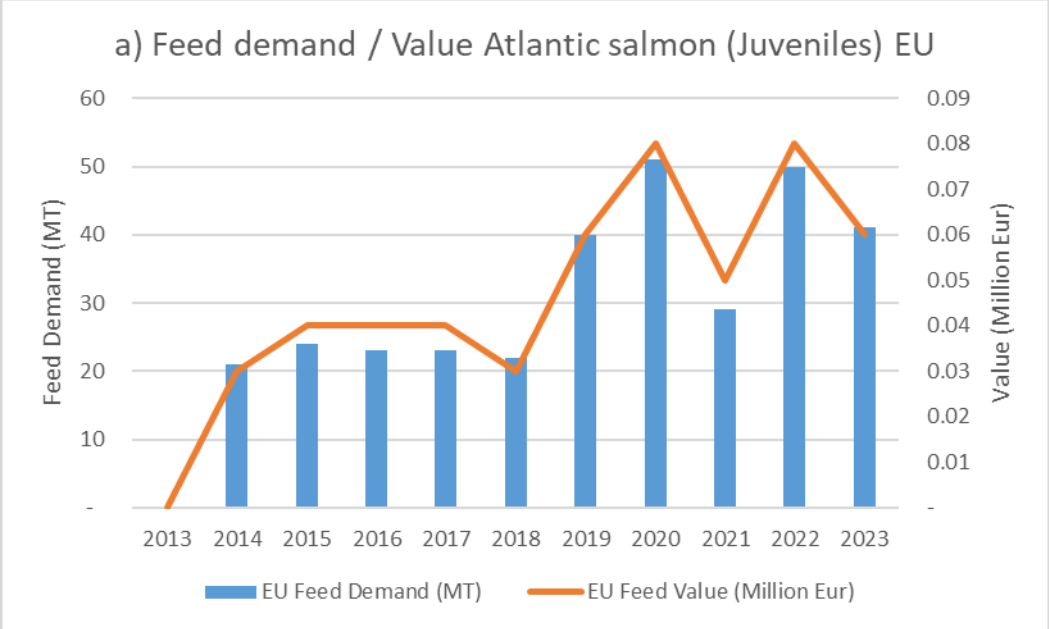
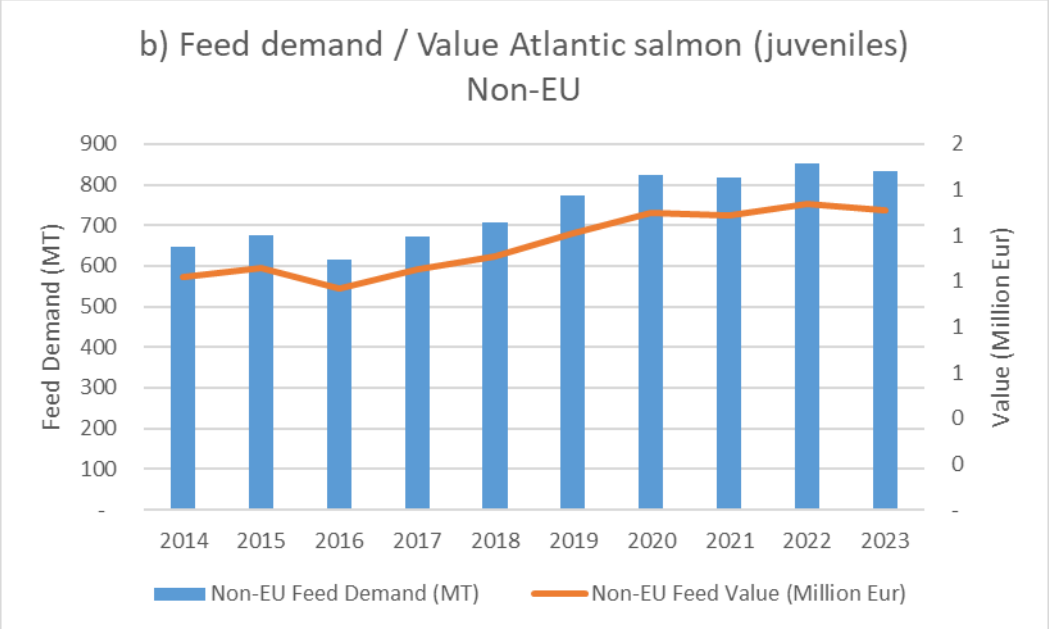


Figure 9 – Feed demand volume/value for Atlantic salmon (juvenile stage)(2013-2023) in the a) EU, b) Non-EU



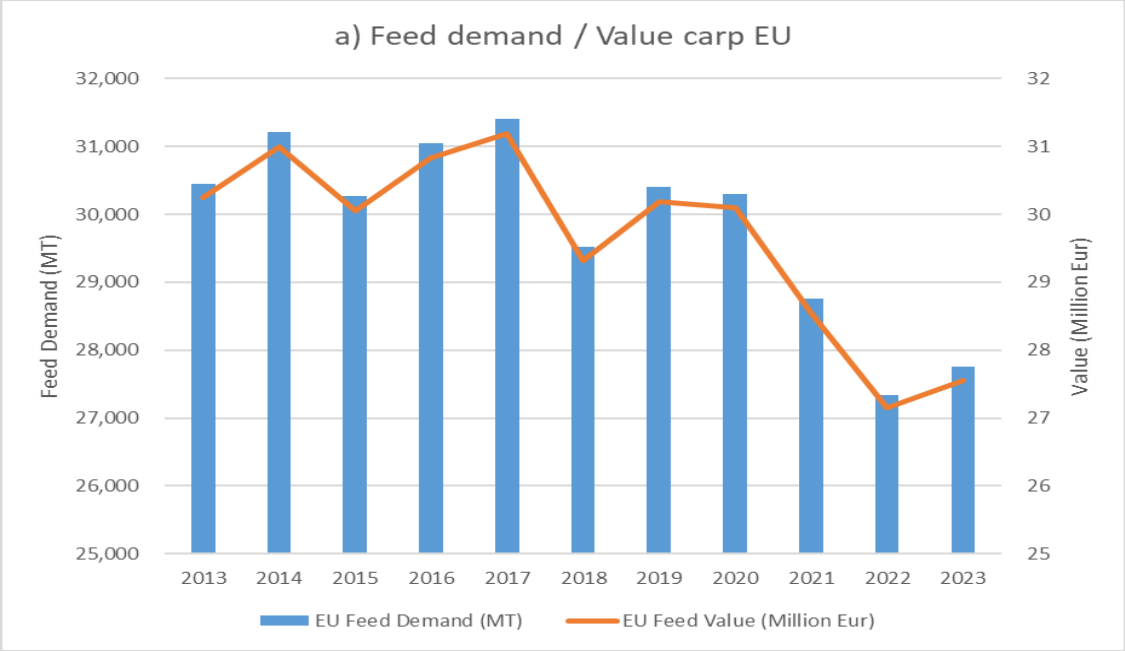


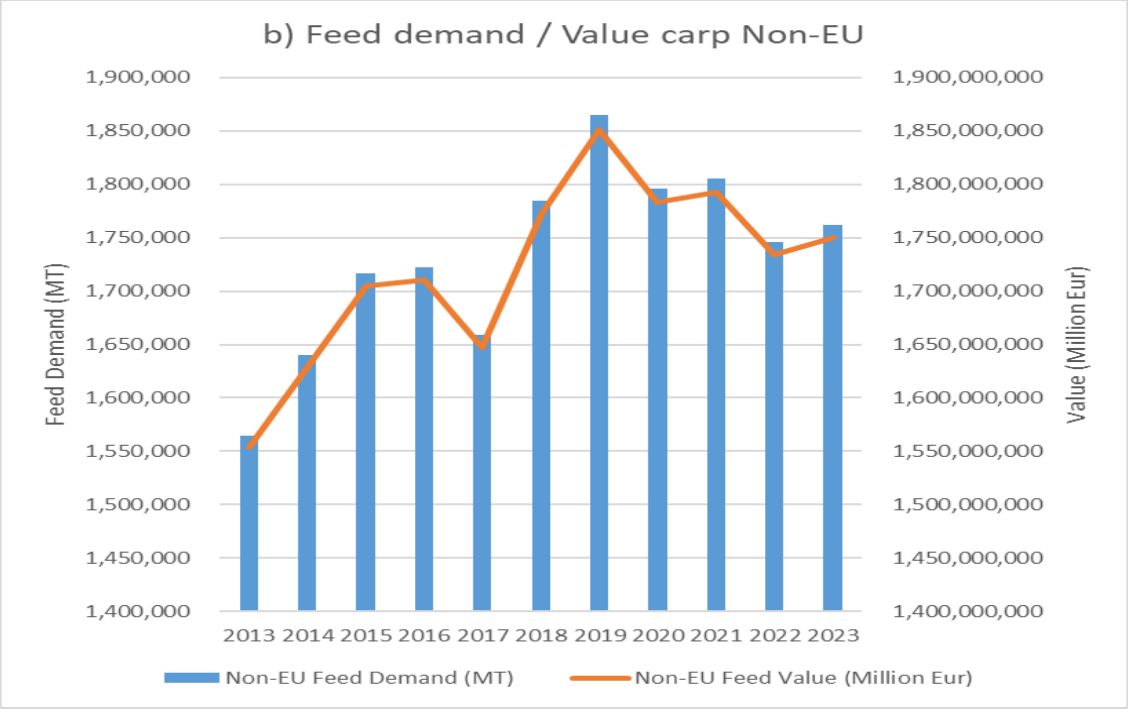
3.1.3. Common carp (Cyprinus carpio)

In the EU, **common carp are fed using both cereal-based feeds**, which are characterized by high feed conversion ratios (FCRs) of around 4.5 (FAO, 2026), **and nutritionally complete extruded feeds** which can deliver FCRs of around 1.75 depending on the formulation (Suprayudi et al. 2022), as detailed in the species-specific section. According to EU Data Collection Framework (DCF) data for Poland, approximately 75% of farms rely on cereal-based feeds, while

around 25% use extruded feeds, sometimes in combination with cereal-based feeds. In the EU there was a demand (2023) for a total of 241,830 tonnes of feed of which 27,751 tonnes (EUR 28 million) is pelleted (Figure 10). Overall, **feed demand has decreased in the EU** between 2013 and 2023 dropping by about 9% from 313,230 tonnes. On a global scale common carp feed demand in the EU is very low, comprising less than 2% of global demand.

Figure 10 – Feed demand volume/value for carp (2013-2023) in the a) EU pelleted feed demand b) Non-EU pelleted feed demand

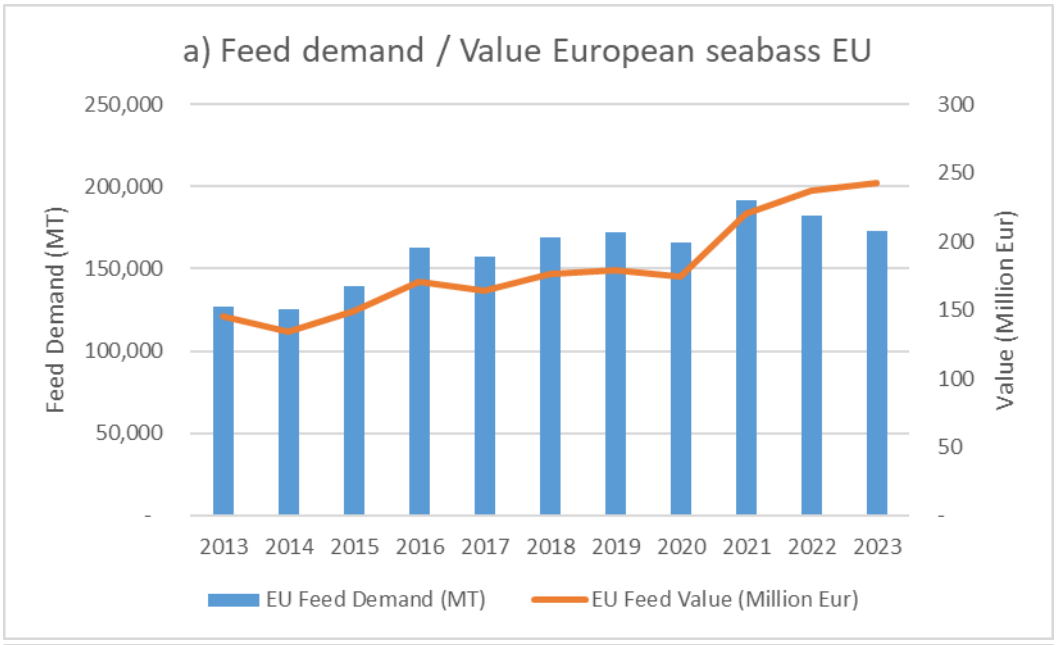


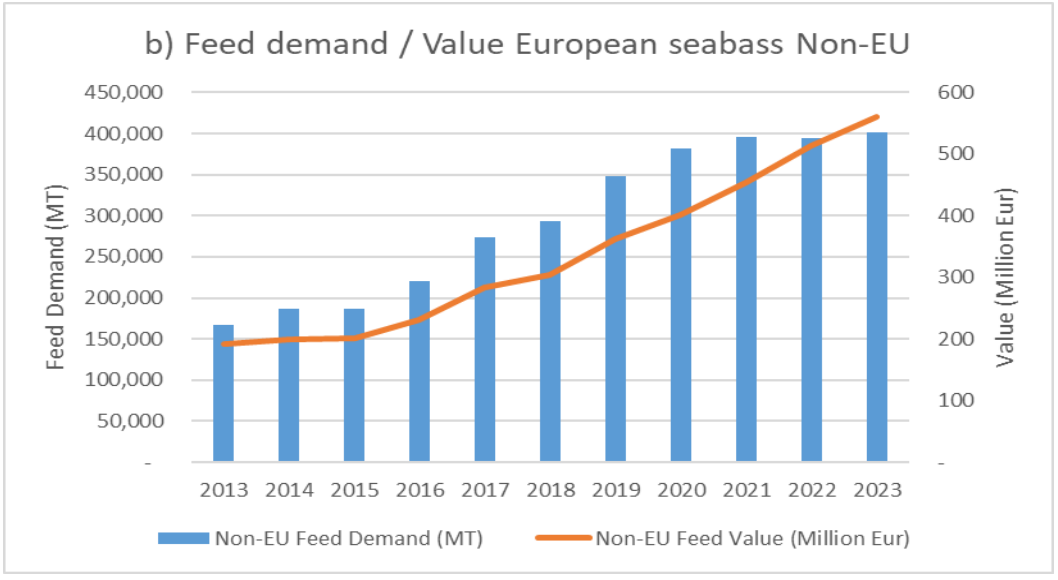


3.1.4. European sea bass (*Dicentrarchus labrax*)

Feed demand of European sea bass peaked in 2021 and has subsequently fallen slightly. The 2021 the EU feed demand volume was 191,304 tonnes and, although not sustained in the following two years, **European sea bass feed demand was seen to increase in volume** from 127,751 tonnes in 2013 to 173,093 tonnes in 2023, an increase of just over 35% (and value from EUR 146.3 million to EUR 192.2 million). However, the relative feed demand of the EU has dropped, with the 2023 figure of 30% of global demand being the lowest in the timeseries as production in non-EU countries has increased. Global feed demand stood at 574,000 tonnes and EUR 804 million in 2023.

Figure 11 – Feed demand volume/value for European sea bass (adult stage) (2013-2023) in the a) EU, b) Non-EU

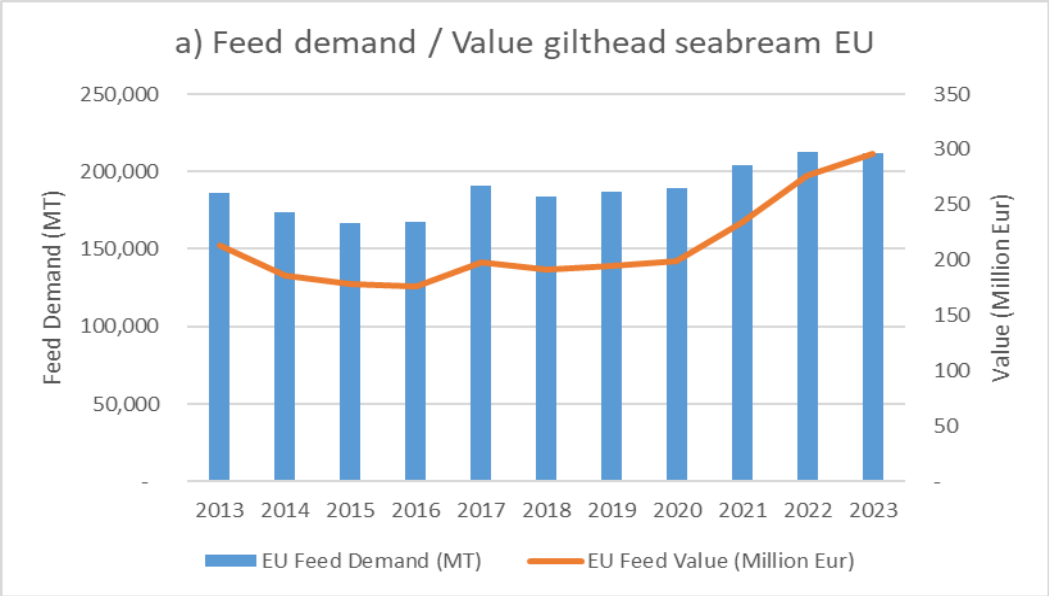


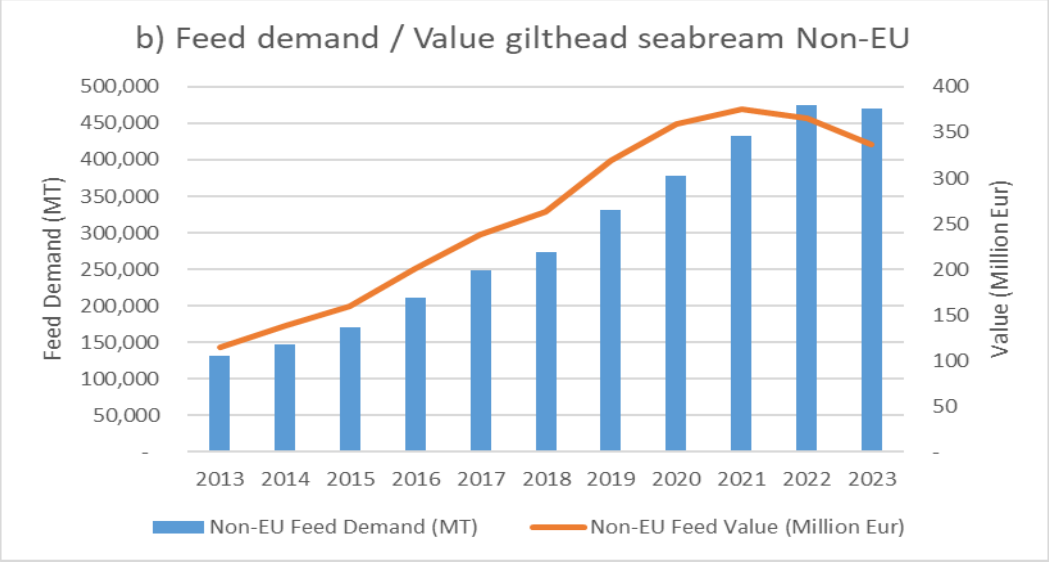


3.1.5. Gilthead sea bream (*Sparus aurata*)

Although globally, gilthead sea bream feed demand has seen a doubling of volume in the last 10 years to 2023, the situation in the EU has not been as dynamic, although **feed demand has increased slightly** from 186,437 tonnes to 211,848 tonnes (a 13.6% increase) with value increasing from EUR 213.5 million to EUR 297 million. As seen with the EU sea bass, the relative proportion of EU to global feed demand for this species has dropped from 59% to 31% between 2013 and 2023 with global demand standing at 682,000 tonnes and a value of EUR 956 million in 2023.

Figure 12 – Feed demand volume/value of gilthead seabream (adult stage) (2013-2023) in the a) EU, b) Non-EU

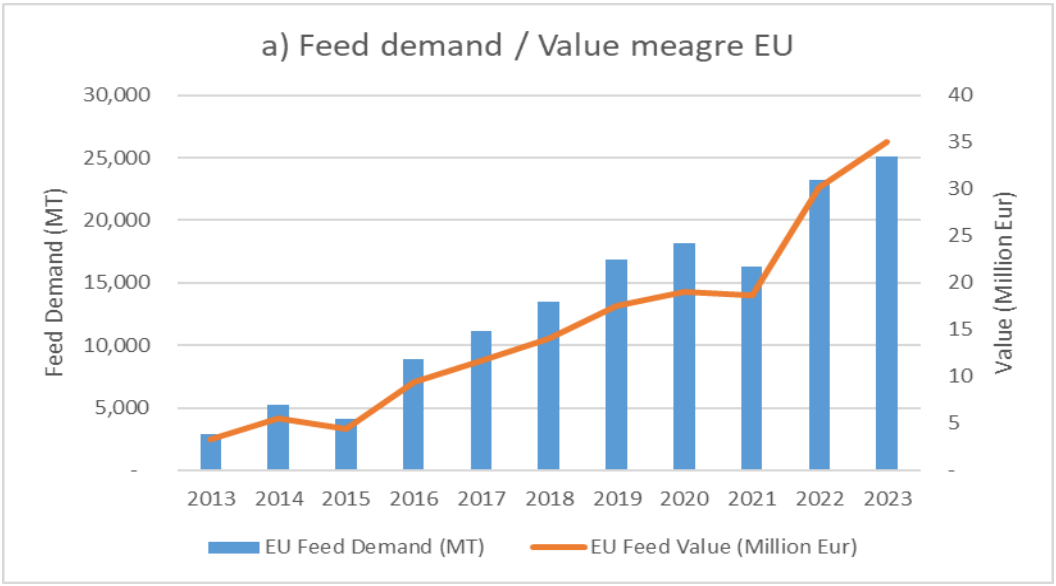


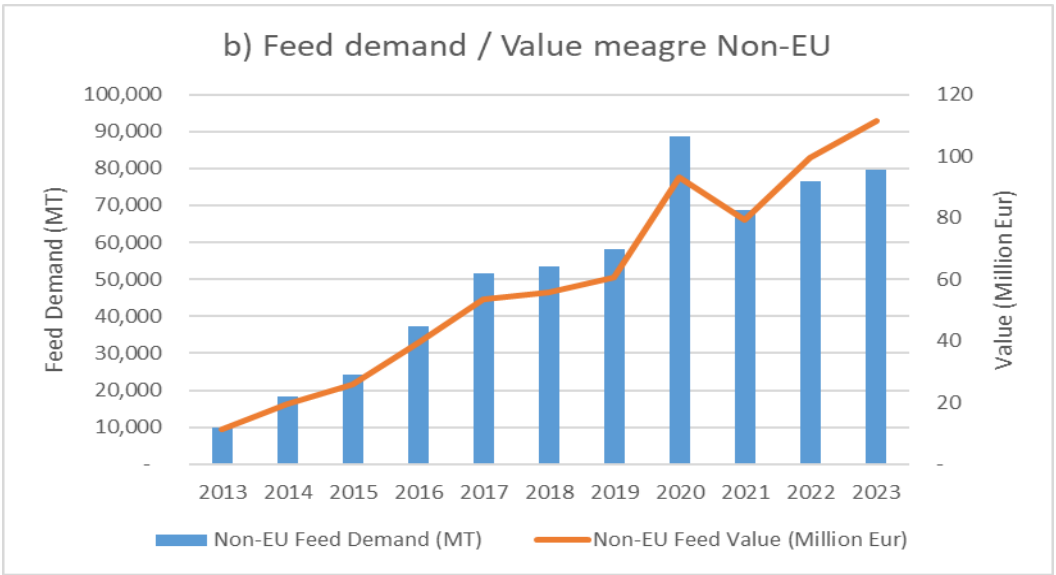


3.1.6. Meagre (*Argyrosomus regius*)

Experimental culture of meagre started at the end of the 20th century, around 30 years after the development of seabream and seabass culture, and there is still a lag in its production volume. However, it has seen a general consistent increase in production volume and thereby feed demand since culture began. **The EU saw a 9-fold feed demand increase within the last decade** from 2,882 tonnes in 2013 and 25,045 tonnes in 2023 (corresponding value of EUR 3.3 million to EUR 28.7 million). Global feed demand increased in a similar fashion and the EU has remained between 18 and 24% of global feed demand between 2013 and 2023.

Figure 13 – Feed demand volume/value of meagre (2013-2023) in the a) EU, b) Non-EU

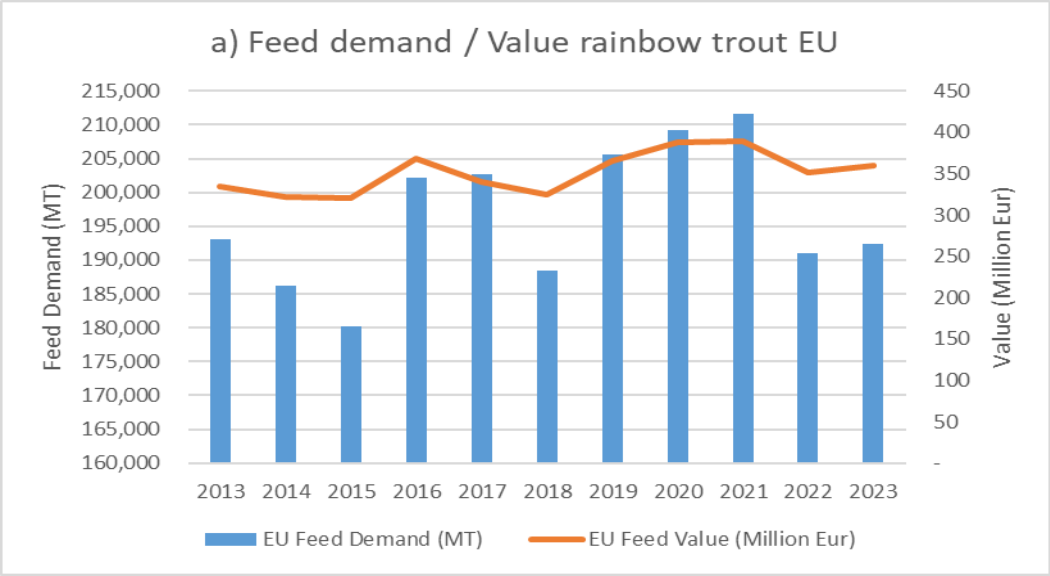


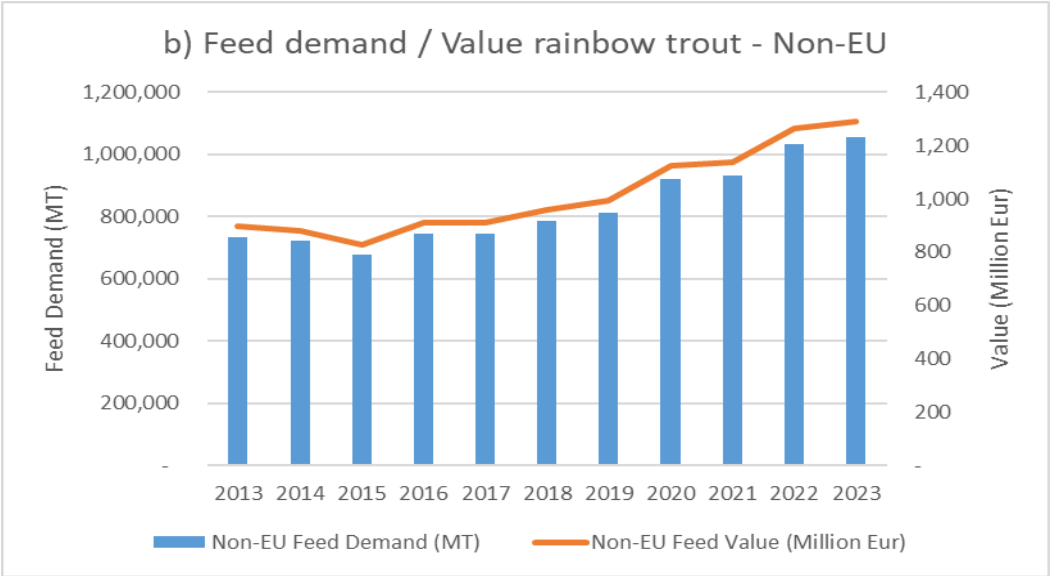


3.1.7. Rainbow trout (*Oncorhynchus mykiss*)

Total annual feed demand for rainbow trout in the EU averaged 196,593 tonnes between 2013 and 2023, with **slight variation from year to year** and a peak demand in 2021 with 211,551 tonnes (and value of EUR 258.3 million (Figure 14). Global rainbow trout feed demand rose from 930,000 tonnes in 2013 to over 1.2 million tonnes in 2023 (EUR 1.13 billion to 1,5 billion) and EU rainbow trout feed demand ranged between 18 and 21% of global rainbow trout feed demand between the years 2013 and 2021; however, in 2022 and 2023, this dropped to 16 and 15% respectively; it is still to be seen if this downward trend continues going forward.

Figure 14 – Feed demand volume/value for rainbow trout (2013-2023) in the a) EU, b) Non-EU

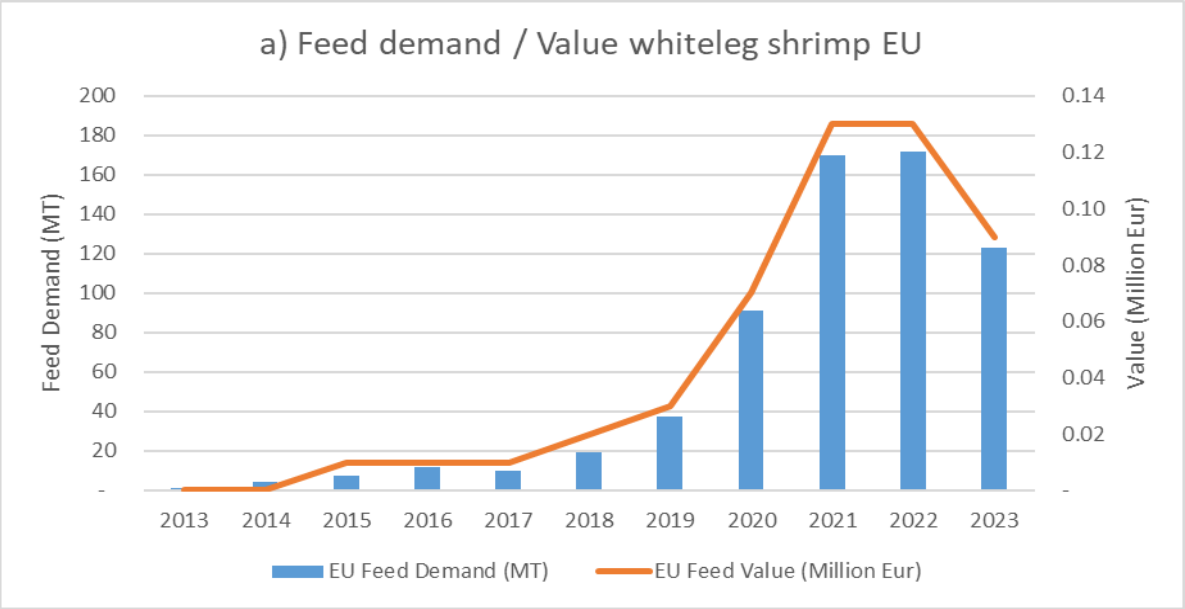


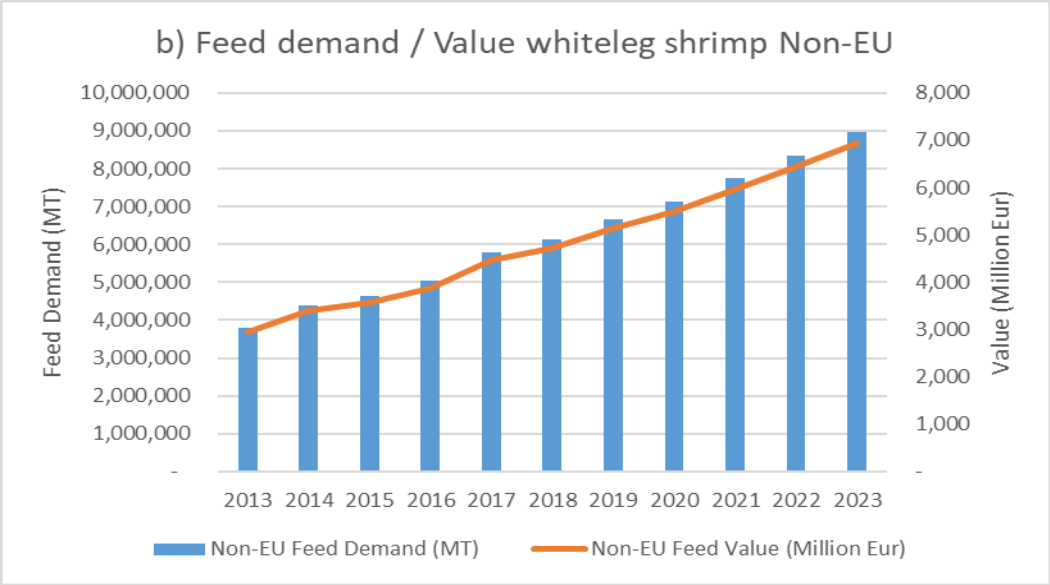


3.1.8. Shrimp (*Litopenaeus vannamei*).

The exponential growth of global shrimp production, which surpassed 7 Mt in 2023, has led to a substantial increase in the demand for shrimp feed. Using an FCR of 1.2, this level of production translates to an estimated feed requirement of approximately 8.4 Mt. Major producers such as China, India, Ecuador, Indonesia, Vietnam, and Thailand are driving this demand, with Asia remaining the central hub of shrimp farming activity. In contrast, However, although the feed demand use has increased significantly over the past 10 years or so, **the EU’s contribution to global shrimp feed utilisation remains negligible**, requiring only about 123 tonnes of feed (with a value of only EUR 90,000) in 2023 (down from a peak of 172 tonnes feed usage in 2022). This stark disparity highlights Asia's dominance not only in shrimp output but also in feed consumption. Global feed demand for whiteleg shrimp stood at almost 9 million tonnes and EUR 7 billion in 2023. EU shrimp feed demand is insignificant when considered globally (with a peak of 0.0022% in 2021).

Figure 15 – Feed demand volume/value for whiteleg shrimp (2013-2023) in the a) EU, b) Non-EU

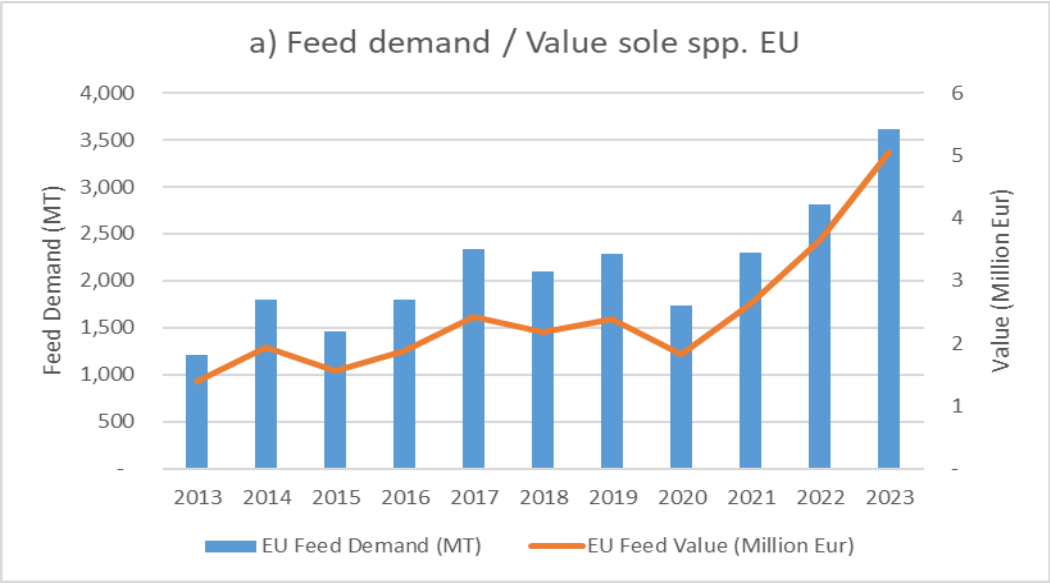


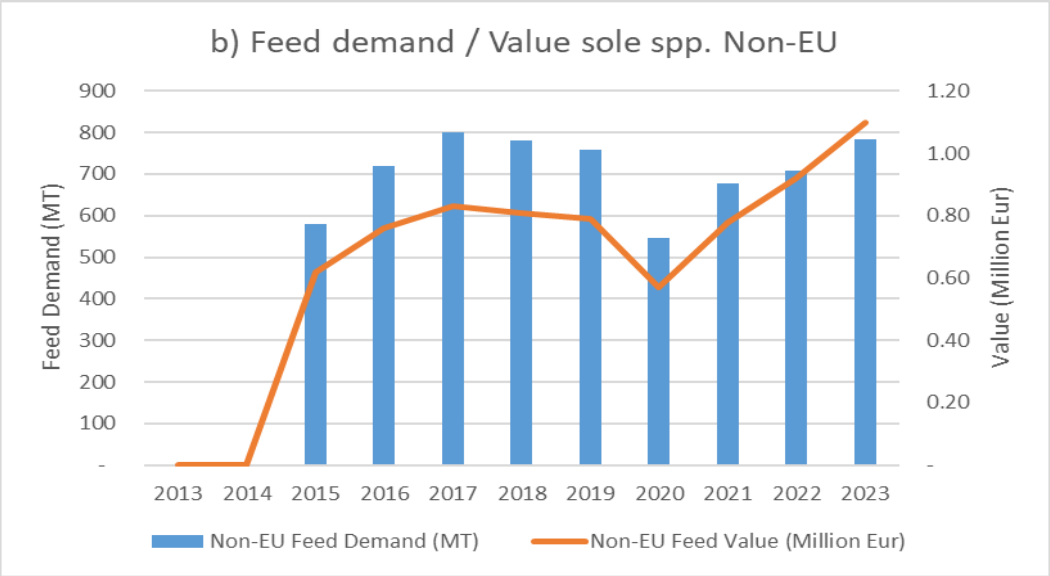


3.1.9. Sole (*Solea solea* and *Solea senegalensis*).

Sole production is still in its early stages compared to the established markets of seabass and seabream. Production has experienced many difficulties including nutrition, stocking density, environment and size variability. This, combined with a ‘thin’ market (Bjørndal et al., 2015) may inhibit major development. However, **since 2020 there has generally been a continued increase in production** (Figure 16), resulting in a threefold increase in EU feed demand (3,618 tonnes vs 1,213 tonnes) in 2023 compared to 2013, equivalent to a corresponding increase in value from EUR 1.4 million to EUR 4.1 million. EU leads the way in sole feed demand with 82% of the 2023 global feed demand (minimum of 73% in 2018). Global feed demand for sole stood at 4,400 tonnes and EUR 6.2 million in 2023.

Figure 16 – Feed demand volume/value for sole spp. (2013-2023) in the a) EU, b) Non-EU





3.1.10. Sturgeon (*Acipenser* spp. and *Huso* spp).

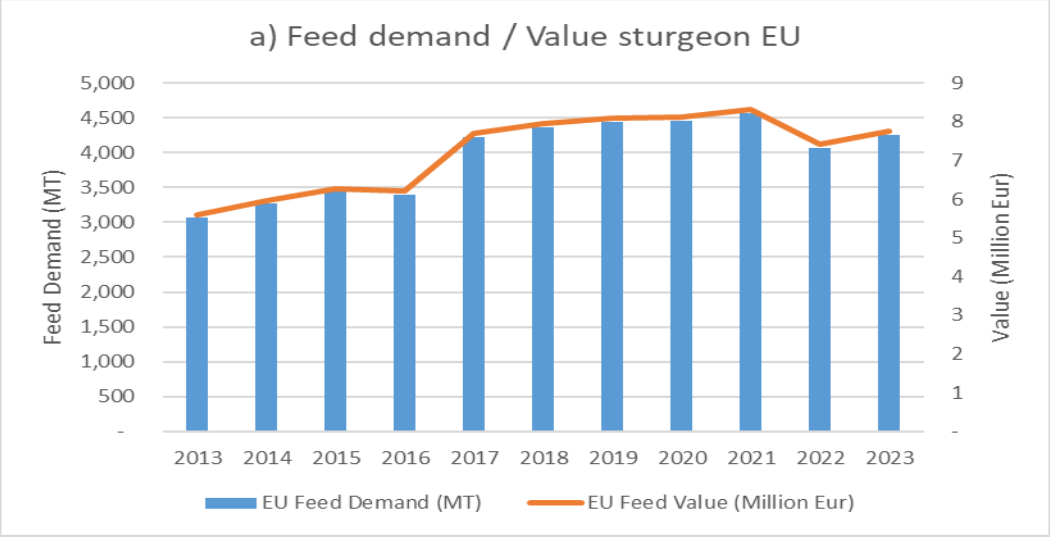
Producing 1 kg of caviar requires approximately 15–30 kg of feed over the full sturgeon life cycle, which typically spans 8 to 10 years. This high feed input results from the species’ long grow-out period, late sexual maturity, and relatively low caviar yield (about 10–15% of body weight).

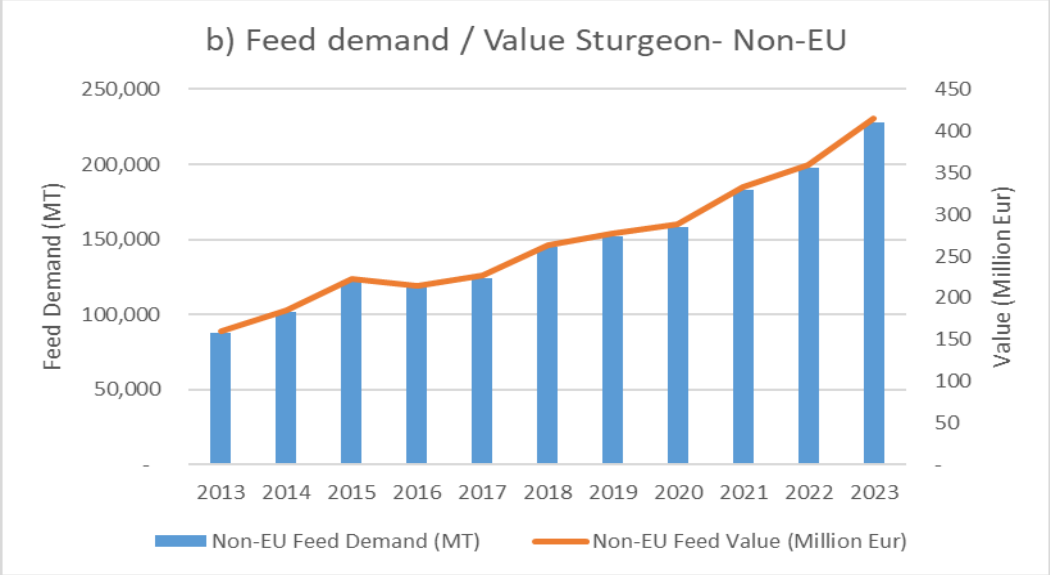
A more detailed analysis of sturgeon production – including both caviar and total fish biomass – enabled the estimation of the number of mature females used for caviar production (annual output increased from approximately 500 tonnes in 2014 to around 1,250 tonnes in 2023) and the production of other

sturgeon categories of males and juveniles (relatively stable at an average of 2,000 tonnes per year).

It was assumed that producing 1 kg of mature female requires 2.25 kg of feed, while other sturgeon categories require 1.3 kg of feed per kg of fish, based on the feed conversion ratio. As a result, **average annual feed use for EU sturgeon farming over the past decade was estimated at approximately 4,000 tonnes**, with an increase of about 40% from 3,064 tonnes (value of EUR 5.58 million) in 2013 to 4,259 tonnes (value of EUR 7.76 million) in 2023. As observed with some other species considered in this document, EU sturgeon feed demand—although increasing in tonnage—has declined as a share of global demand (accounting for only 1.8% in 2023, compared to 3.4% in 2013) as production has expanded elsewhere. Global feed demand is estimated to have amounted to 232,000 tonnes at a value of EUR 423 million in 2023.

Figure 17 – Feed demand volume/value of sturgeon spp, (2013-2023) in the a) EU, b) Non-EU



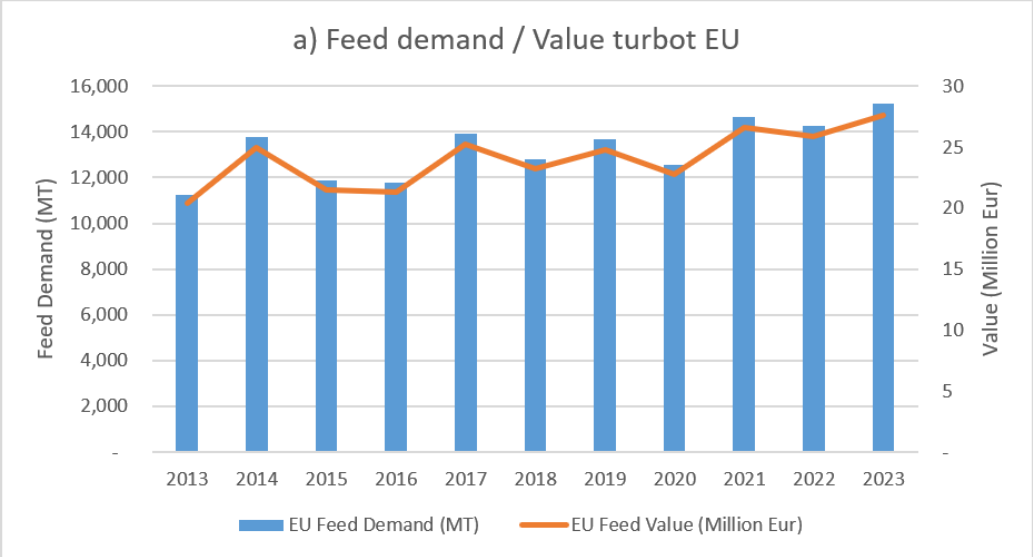


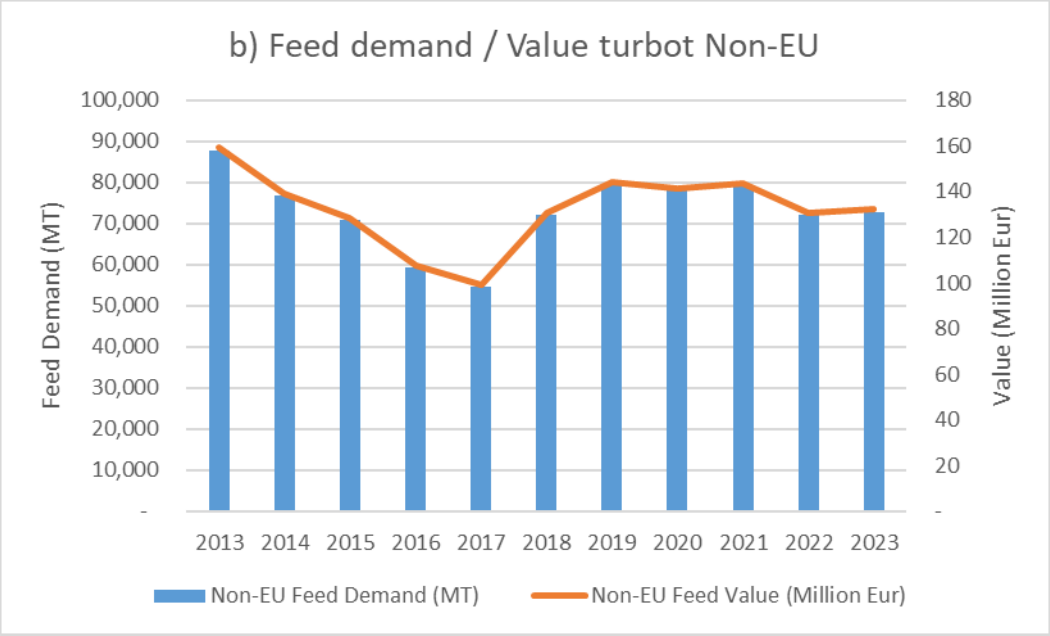
3.1.11. Turbot (*Scophthalmus maximus/Psetta maxima*).

EU turbot production has increased gradually in the last decade. The reasons for a lack of significant growth are complex and involve biological, environmental, technological, political and social factors, interrelated with the economic-financial landscape (Figure 18). Nonetheless, **feed demand in the EU increased from 11,232 tonnes in 2013 to 15,220 tonnes in 2023**, an increase of just over 35%. The corresponding increase in value went up from EUR 20.4 million to EUR 27.6 million. EU turbot demand contribution to global demand has actually increased since the beginning of the time series being discussed (11% in 2013), being a relatively stable 16-17% in the final three

years 2021-2023. Global feed demand stood at 88,100 tonnes and EUR 160 million in 2023.

Figure 18 – Feed demand volume/value of turbot (adult stage) (2013-2023) in the a) EU, b) Non-EU





3.2. Aquafeed market dynamics

3.2.1. EU and global feed producers

The global aquafeed market is highly consolidated, with a few major producers dominating the industry. Competition is intense among these leading

suppliers, who leverage technological innovations, strategic partnerships, and acquisitions to strengthen their market position. This demands that companies are continuously innovating to offer superior or novel products and gain market share. Typically, aquafeed will be one of several markets in the company’s portfolio – amongst other farmed and/or domestic animals feeds, or agriculture/aquaculture products. **Most aquafeed producers have a global reach, reflecting the production of the species** (for example, salmon feeds) rather than geographical specialisation. For aquafeed manufacturers, logistics and economics encourage the location of feed mills in areas of aquaculture production (Boyd & McNevin, 2022; Tacon, 2020), particularly where the industry is substantial. Therefore, **a country’s aquaculture production is likely to reflect its aquafeed production**.

Based on available information (through company reports), industry consultation, and market analysis figures, the main EU and global aquafeed producers are presented in Table 5 and Table 6 respectively. Getting reliable aquafeed production data by company can be challenging, **for many feed producers, aquafeeds are only a (potentially small) part of their production** and reporting sometimes covers multiple feed types, failing to separate volumes of aquafeed production. Secondly, there is no global register of aquafeed producers (unlike the IFFO, for example), nor a remit by which producers should register. Whilst a global register does not exist there is a compulsory register for approved animal feed producers within the EU ([50]).

([50]) https://food.ec.europa.eu/food-safety/animal-feed/feed-hygiene/approved-establishments_en

Table 5 – Summary of main EU aquafeed producers

Company	Headquarters/operational countries	Summary	Sales (USD)	Species	Aquafeed Production volume (tonnes)
Aller aqua	Denmark, 70	Aquafeed producer	0.3 million (2022)	30+ species including salmon and trout	340,000
Biomar	Denmark, 90	Biomar is a prominent fish food producer, offering a diverse range of feed products for various fish species.	1.1 billion	Atlantic salmon, sea bass, sea bream, shrimp, sturgeon, meagre, sole, turbot, trout and others not relevant to report	1,437,000
Coppens	Netherlands, 120	Coppens is the aquafeed division of Alltech, an animal nutrition company.	676 million (2020)	trout, sturgeon, salmon, seabream seabass, carp.	70,000
Nutreco:	Netherlands, 80	This company encompasses several brands, including Skretting, and focuses on providing feed solutions for aquaculture and livestock.	21.5 billion (Nutreco),	54 species including whiteleg shrimp, Atlantic salmon, carp, meagre, rainbow trout, sole, sea bream, sea bass, sturgeon, tuna, turbot	2.4 million (Skretting)

Table 6 – Summary of main global aquafeed producers

Company	Headquarters/operational countries	Summary	Sales (USD)	Species	Aquafeed Production volume (tonnes)
ADM (Archer Daniels Midland Company):	USA, 200	ADM is a major player in the agricultural sector and produces various feed products, including aquafeeds.	85.53 billion (2024) (including non-aquafeed)	Fish and shrimp	-

Company	Headquarters/operational countries	Summary	Sales (USD)	Species	Aquafeed Production volume (tonnes)
Alltech	USA Alltech, 120	Known for its nutritional products, Alltech also offers aquafeed solutions that include functional materials aimed at improving fish health and growth.	Alltech 2 billion (2020), Coppens 676 million (2020)	trout, sturgeon, salmon, seabream seabass, carp.	70,000
Benchmark Holdings (Inve)	Benchmark -UK, Inve -Belgium, 27	Benchmark Advanced Nutrition operates in the global market as INVE aquaculture. They produce specialist feeds, additives and nutritional health products.	16 million	Marine fish and shrimp	-
Cargill:	USA, 70	A global company, delivering agricultural products and services, Cargill produces a wide range of aquafeed products under the several brands	160 billion (including non-aquafeed)	Salmon, shrimp, trout (and 9 other species not relevant to report)	1.8 million (2023)
CPF	Thailand, >50	Charoen Pokphand Foods Public Company Limited is an agro-industrial and food conglomerate. It is one of the world's largest producers of feed and some fish and shrimp.	4.0 billion (including non-aquafeed)	Shrimp (and 4 other species not relevant to report)	-
Mowi	Norway, 26	Mowi is the world’s largest salmon producer with a global market share of 20% and manufactures its own aquafeed.	52 million (feed alone)	Salmon	527 751 (2023)
Ridley corporation (Ridley aqua feed)	Australia, 2	Ridley corporation is an animal food manufacturer (for the agricultural and domestic markets). Ridley Aqua Feed is the division responsible for fish food production.	0.82 billion	Shrimp, trout, salmon	-
Skretting	Norway 80	Skretting are a division of Nutreco	2.83 billion (Skretting) (2020)	54 species including whiteleg shrimp, Altantic salmon, carp, meagre, rainbow trout, sole, sea bream, sea bass, sturgeon, tuna, turbot	2.4 million

3.2.2. Aquafeed market trends

The European (EU and Non-EU) aquaculture sector has demonstrated resilient growth over the past five years, with a 2.1% rise in aquafeed production in 2024 continuing that trend (Alltech, 2025). This increase is underpinned by strategic adaptations to sustainability demands, technological advancements and market dynamics. Increases in the production of Atlantic salmon, European sea bass and gilthead seabream are driving growth by commanding premium prices around the world. Additionally, **lower aquafeed costs have eased margins for European producers** (Alltech, 2025). In 2024, Europe (EU and Non-EU) produced 9.1% (4.8 Mt) of the global production of aquafeed. Whilst the EU is reliant on imports of aquafeed materials such as soy, most EU aquafeed consumption comes from EU feed mills (Stakeholder consultation) indicating a high level of self-sufficiency in this regard. Interviews with industry stakeholders suggested that exports of EU aquafeed are not expected to increase significantly in the future with stricter rules and regulations as well as price competitiveness compared to locally produced feeds seen as obstacles.

Table 7 – Global aquafeed production

Region	2024 Feed tonnage (million tonnes)	2023 Feed tonnage (million tonnes)	Growth (million tonnes)	Growth (%)
Africa	1.726	1.582	0.143	9.10%
Asia-Pacific	37.074	37.721	-0.647	-1.70%
Europe	4.775	4.676	0.099	2.10%
Latin America	6.831	6.992	-0.162	-2.30%
Middle East	1.016	1.023	-0.006	-0.60%
North America	1.309	1.359	-0.05	-3.70%
Oceania	0.235	0.215	0.02	9.30%
Total	52.966	53.568	-0.602	-1.10%

Source: Alltech 2025

Estimates of the global aquafeed market value vary considerably – between USD 52.51 billion (Modor Intelligence, n.d.) and USD 183.0 billion (Imarc, n.d.) in 2024. However, **all market analysis predicts continued growth** - at a CAGR of 5.10- 7.46% - within the next 5 years.

An estimated 1.4 billion tonnes of compound animal feed were produced globally in 2024 (Alltech, 2025); 3.7% of which (52.97 Mt) was aquafeed (not including live foods and 'trash' fish). Whereas total animal feed production has

shown an increase since 2023, aquafeed has declined slightly by 1.1%. This statistic, however, conceals considerable regional divergence, belying gains in Latin America, African and European markets. Considerable decreases in the dominant markets of Asia-Pacific and North America (due to disease, climate events, costs and low market prices) influenced the global mean.

3.3. Aquafeed materials

The range of aquafeed materials has expanded enormously in the last few decades, in response to a greater understanding of their biological implications (e.g. nutrition, health effects), supply chain pressures of traditional materials, food security objectives, sustainability targets and changing legislation/regulation. Aquafeed producers must strategize in the long to medium-term on the optimum combination of materials in their diets to achieve the best performance, market advantages, and profitability. Meanwhile, the impact of availability might require slight modifications on an almost daily basis within the feed mill itself. This section will review the factors that are considered in deciding which materials to include. A summary of key material information is provided in Annex 7.

Compared with the nutrition of terrestrial farm animals, **understanding of the feed requirements of aquatic organisms is relatively new**, and there is constant progress in this area. While there are fundamental similarities in the nutrients (sources of protein, lipids, carbohydrates, and micronutrients), the enormous diversity of aquatic organisms presents particular challenges. The ever-expanding range of cultured species demands new formulations, and the increased knowledge of nutritional effects refines and develops the range of materials that can be used. Recently, crop feed formulations have improved, allowing complete substitution of animal-based diets with plant-based ones in some species. However, these results are species-specific, and total substitution with plant-based materials can still negatively affect survival and growth rates in other species. Improved inclusion rates are supported by modern advances in feed material processing including the use of additives such as animo acids, flavourings, and vitamins to address nutritional, palatability, and digestibility constraints. Furthermore, genetic technology such as precision breeding / gene editing, and genetic modification can be developed that specifically address challenges of incorporating plant-based products into aquafeeds, such as the naturally low occurrence of omega-3 long chain polyunsaturated fatty acids in most agricultural feed materials (Napier and Betancor, 2023). **Questions however remain about the increased production of terrestrial plant-based materials** given potential requirements for increased stress on land, water, and phosphorous resources (Malcorps *et al* 2019).

Many common feed materials are known by multiple names, this can be due to regional differences, changes in description over time, different levels of processing of the same material, and commercial versus agricultural terminology. Readers may be familiar with materials under different names to those used in the report and to aid understanding please see Table 8 for a list of the most commonly referenced materials in the report and other terms that are used in the literature. Where possible one term is used to describe each material in the report however when analysis is based on sources which use alternative descriptions these are retained to ensure clarity on the exact material that is being referred to.

An example of this can be seen in the use of rapeseed and canola. Canola is a variety of rapeseed (specifically a low erucic acid variety), but both terms are often used interchangeably. The EU catalogue ([51]) of feed materials refers only to rapeseed but the two materials are often referred to as two distinct products in the literature, and they have different prices on the global market therefore both rapeseed and canola are referred to in the report.

Table 8 - Alternative terms used for some of the feed materials mentioned in the report

Material Category	Material	Other terms used
Rapeseed	Rapeseed oil	Canola oil
	Rapeseed cake	Rapeseed expeller
	Rapeseed meal	Canola meal
Soy	Soybean meal	Soya (bean) meal
	Soybean oil	Soya (bean) oil
	Soybean protein concentrate	Soya (bean) protein concentrate
	Fermented soybean meal	Fermented soya (bean) protein (concentrate)
Maize	Maize gluten feed	Corn gluten feed
Wheat	Wheat gluten meal	Vital wheat gluten
Barley	Brewers spent grain	Brewer’s grain
Porcine	Porcine meat and bone meal	Porcine by-product meal
Microbial biomass	Single cell protein	Microbial protein
	Yeast	Brewer’s yeast, baker’s yeast, yeast biomass

Self-sufficiency of supply is a key component of the sustainability of the EU aquaculture sector, and the self-sufficiency ratio of key EU aquafeed materials can be found in Figure 19 with further detail on production and consumption of feed materials provided in annex 4

([51]) Commission Regulation (EU) 2017/1017

Figure 19 - Self-sufficiency ratio of key aquafeed materials in the EU 2015 and 2023

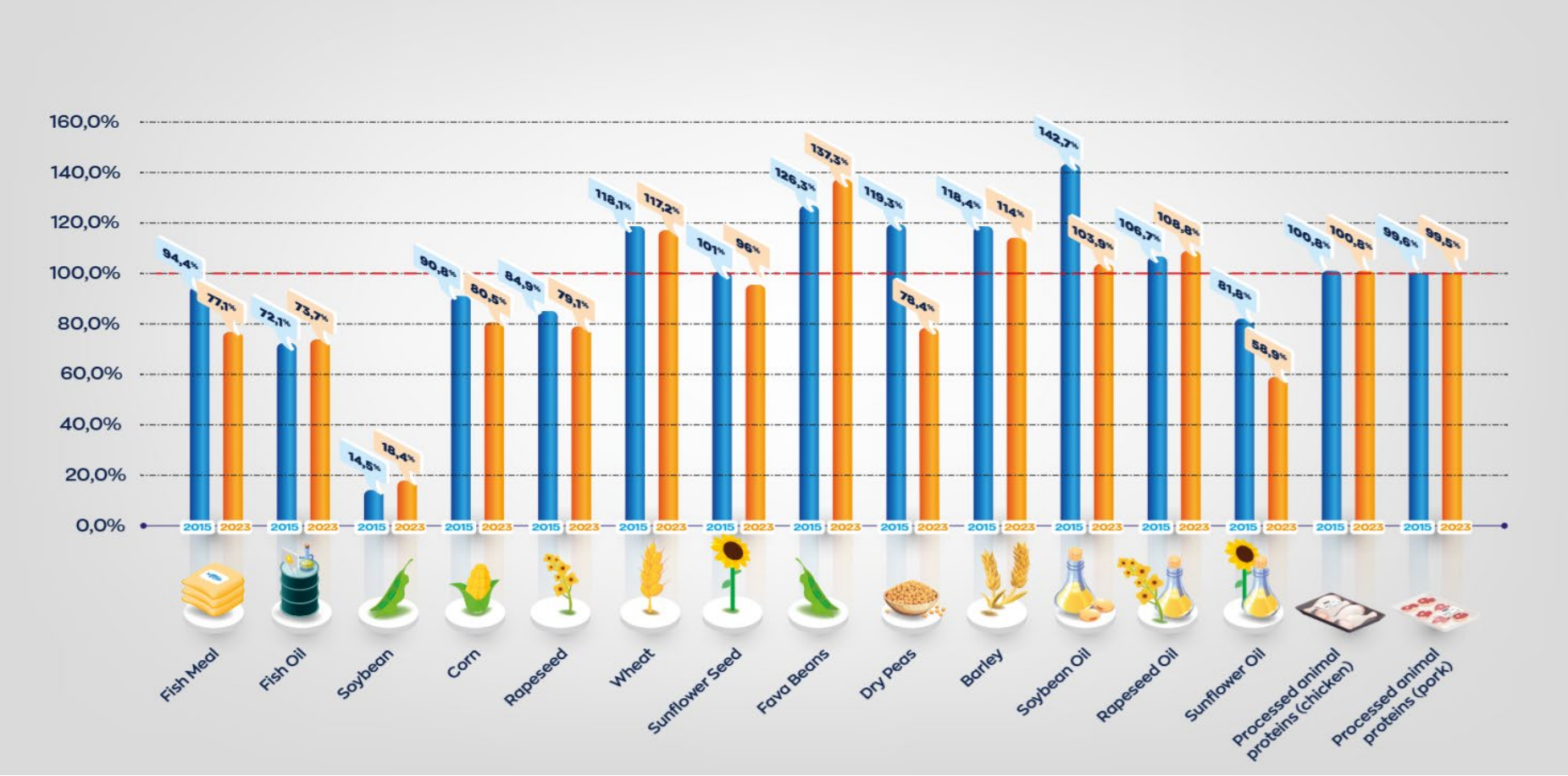


Figure 20 - Summary of key feed material groups

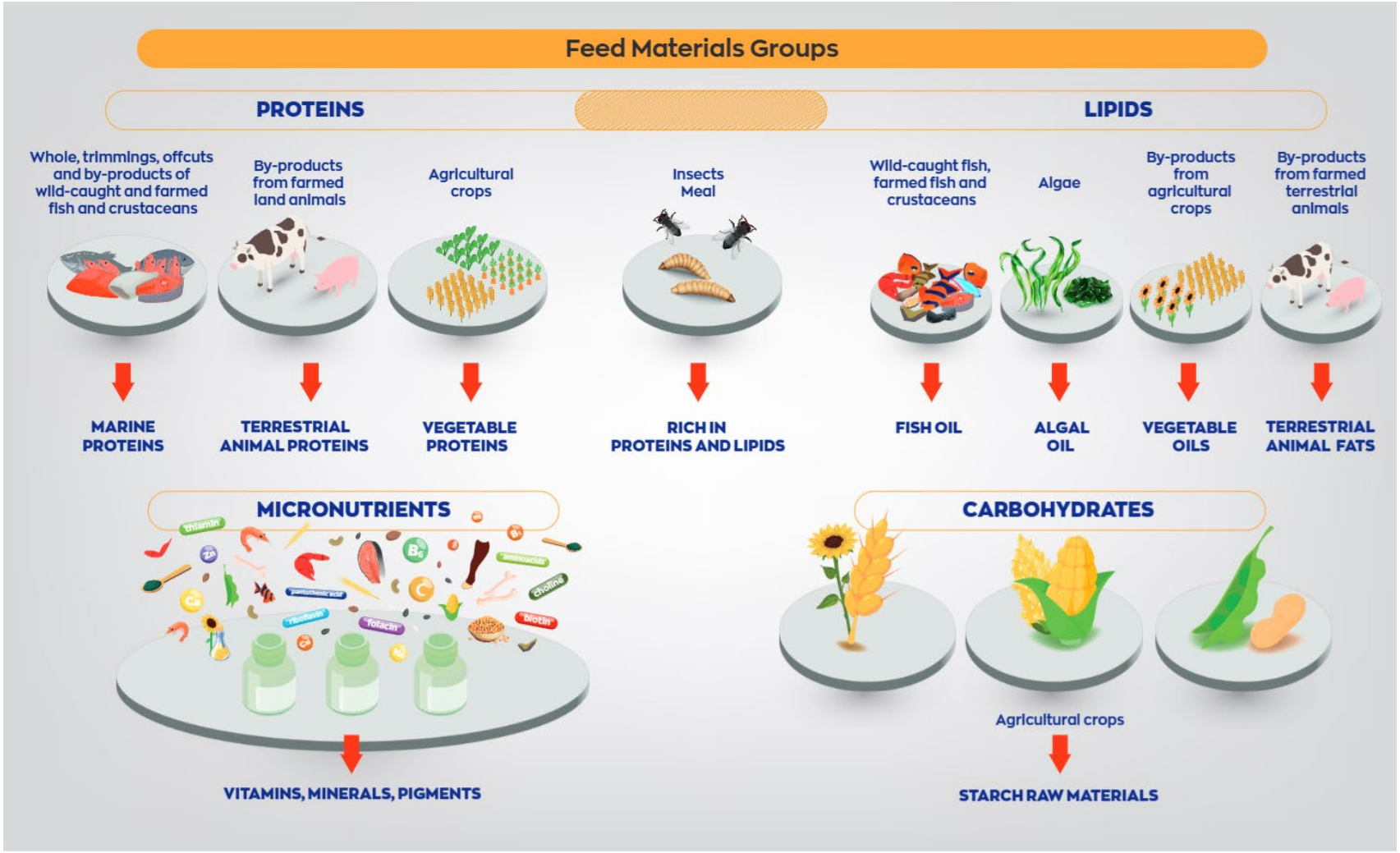
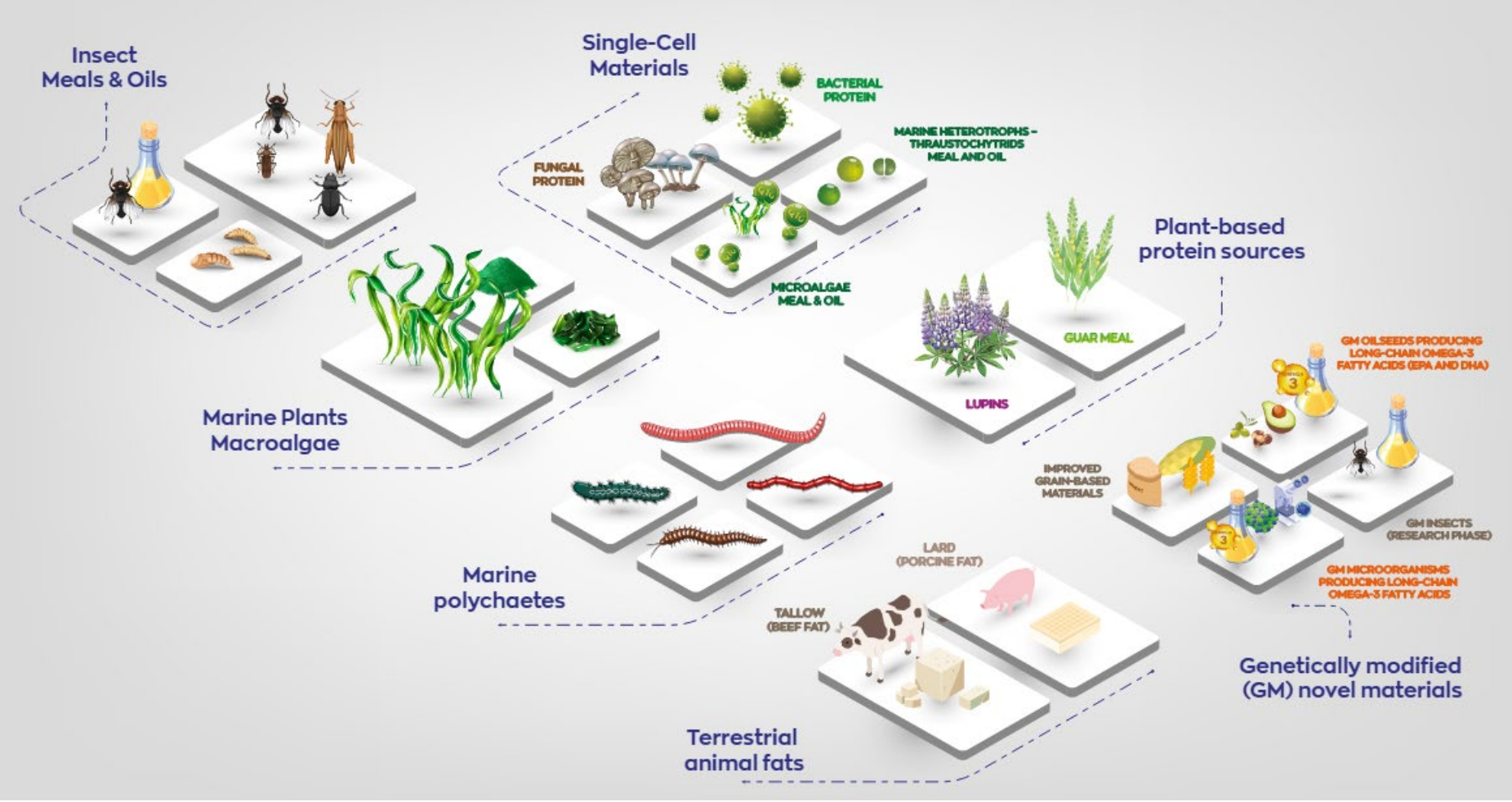


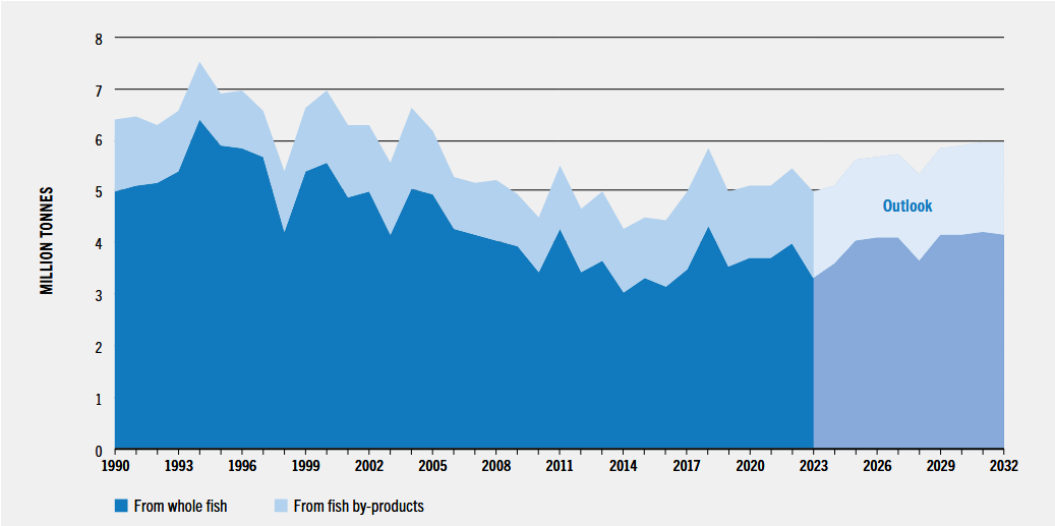
Figure 21 - Summary of key novel and emerging feed materials



3.3.1. Fish meal

Although showing high interannual variability and volatility, **global fishmeal and fish oil production has remained relatively stable since the mid-2000s** following a considerable decrease from the 1990s. Significant increases in production are unlikely to occur in the future as most stocks are now fished at the Maximum Sustainable Yield (MSY). Growth in total fishmeal production may increase with the increased and more efficient usage of fish by-products, while **most wild capture stocks are reaching a point of plateau and so increases may not be significant** (Figure 22).

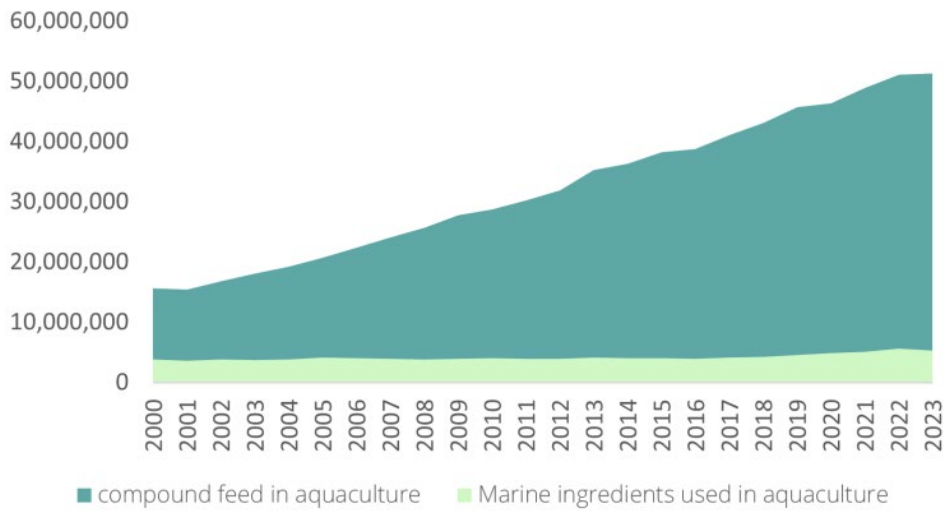
Figure 22 – World production of fishmeal (1990-2023) and projected production volumes to 2032



Source: FAO (2025a)

Despite this, the total **production of compound aquafeed has continued to increase** in line with the continued growth of aquaculture worldwide, with feed formulators utilising non-marine sourced materials (Figure 23).

Figure 23 – Production of aquafeed (tonnes) (2000-2023)



Source: IFFO (2025)

These non-marine material sources include a range of products (outlined later in this chapter), though fishmeal and fish oil will continue to play an important role in aquafeed production given their favourable nutrient profiles, availability and commercial importance.

According to EUMOFA (2025) estimates, the average annual production of fishmeal in the EU was approximately 430,000 tonnes during the period 2007–2017, while in the period 2018–2022 it reached approximately 480,000 tonnes per year. According to the most recent data (EFFOP, 2024), approximately 87.8% of fishmeal produced in Europe is used by the aquaculture sector. Assuming the same ratio for the EU, it can be estimated that **around 420,000 tonnes of fishmeal produced within the EU is annually destined for aquafeed production**.

The raw material for fishmeal production in the EU largely consists of small pelagic fish species (such as sandeel, sprat, blue whiting, boarfish, and herring), alongside trimmings from fish processing industries (EUMOFA, 2025). The importance of herring and blue whiting for both fishmeal and fish oil can be seen in feed company reports with Biomar reporting these two species make up 17.8% and 14.7% of total marine feed material volumes respectively ([52]). **Blue whiting has made up nearly half of Northern European fishmeal production** and the sustainability status of this species is a key consideration for future material sourcing ([53]).

([52]) Biomar 2024 Sustainability Report

([53]) Skretting 2024 Impact Report

Approximately **100 kg of raw materials yield around 20 kg of fishmeal and 5 kg of fish oil**; 40% of fishmeal was derived from trimmings in 2023; depending on the source (whole fish or trimmings) (EFFOP, 2024). This is an important distinction; firstly, all subsequent values report 'gross' fishmeal ([54]) – approximately 60% of which is from fisheries; secondly, fishmeal imports may be reduced by minimising the gross fishmeal / oil fraction in aquafeeds, or by increasing the use of trimming derived fishmeal. It is important to emphasise that by-products from the salmon processing sector are typically segregated and does not enter fishmeal production intended for aquafeed used in salmonid farming. This segregation due to practices defined by the animal byproducts framework in response to the Bovine Spongiform Encephalopathy (BSE) outbreak. The extension of this framework to aquaculture is not without criticism and there are calls to use same species fish hydrolysate within aquafeeds (Sandbakken et al., 2023).

Eurostat-Prodcom (2025) data for the production code 10204100 – Flours, meals and pellets of fish or of crustaceans, molluscs or other aquatic invertebrates, unfit for human consumption shows lower (underestimated) values. This discrepancy may be partly due to missing data from countries such as Ireland and Germany. Nevertheless, the data from other Member States allows for the identification of certain production trends:

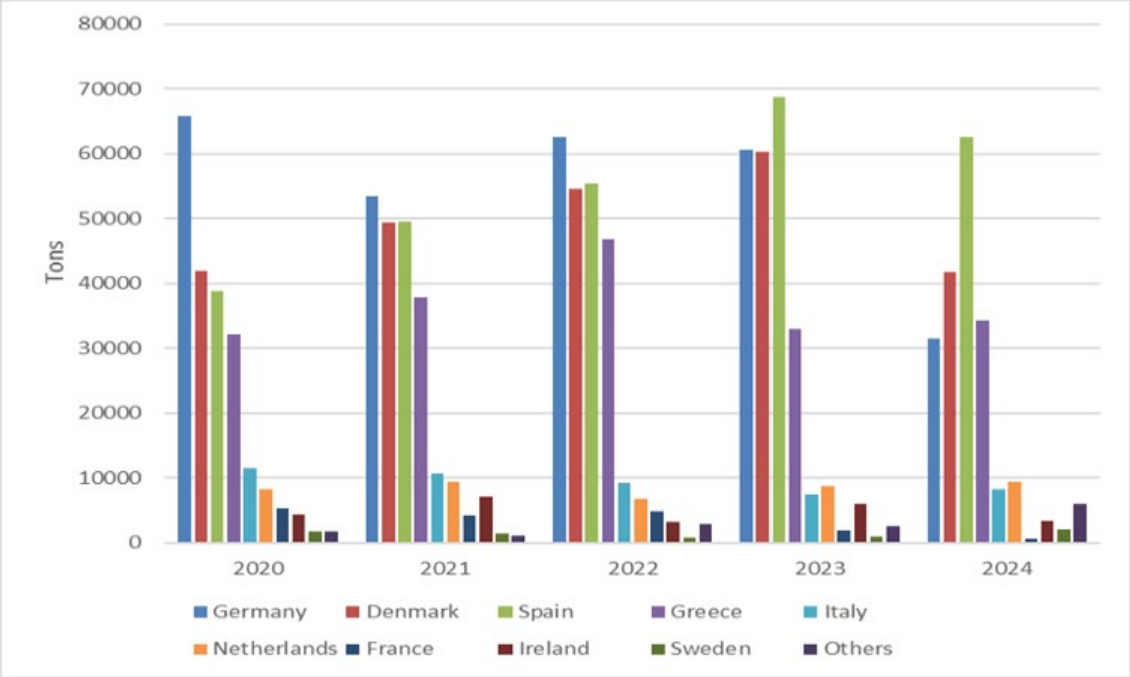
- Denmark is by far the dominant producer, with an average annual production of approximately 209,000 tonnes—accounting for most of the EU's fishmeal supply.
- Other key producers include Spain (average ~47,000 tonnes/year), Latvia (~13,300 tonnes/year), France (~21,000 tonnes/year in years 2019-2023), Portugal (~6,700 tonnes/year), and Poland (~6,000 tonnes/year).
- Smaller contributions were reported from Estonia (~2,800 tonnes/year), Finland (~1,100 tonnes/year), and Lithuania (~750 tonnes/year).

Between 2020 and 2024, imports of fishmeal (code 2301200) into the EU show a slight downward trend. In 2024, 199,457 tonnes were imported, compared to 250,139 tonnes in 2023. Nonetheless, **imports have shown strong fluctuations**; for example, 211,441 tonnes were imported in 2020. In contrast, the trend in terms of value is positive in the period 2020 – 2024. Imports increased from EUR 277.4 million to EUR 319.3 million. In 2024, Spain is the main importer in terms of volume (31%), followed by Denmark (21%), Greece (17%) and Germany (16%). Spain is also the main importer in terms of value (31%), followed by Denmark (24%), Greece (18%), and Germany (18%). **Exports, in volume, follow a slightly declining trend.** They decreased from

([54]) Total fishmeal use including fishmeal from whole wild caught fish, trimmings and other by-products from the fisheries and aquaculture industries

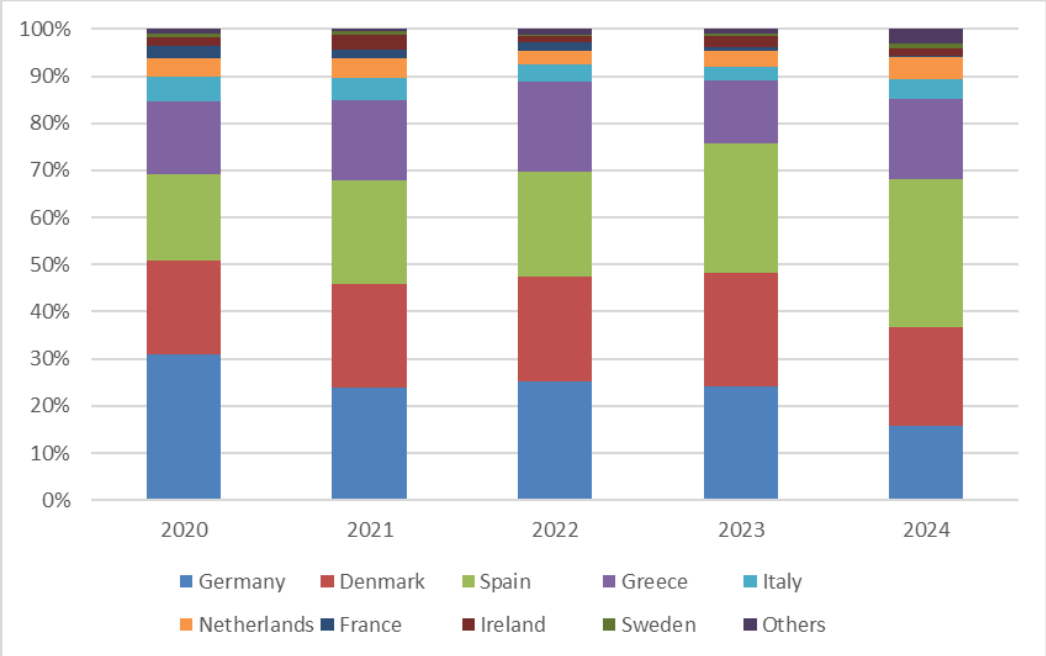
174,256 to 169,675 tonnes between 2020 and 2024. In contrast, **exports in terms of value have increased**, rising from EUR 261 million to EUR 355 million during the study period. The figures below show the evolution of imports by main Member States in absolute volume and percentages.

Figure 24 – Main EU importers of fishmeal and volume imported (tonnes) (2020-2024)



Source: EUMOFA (2025)

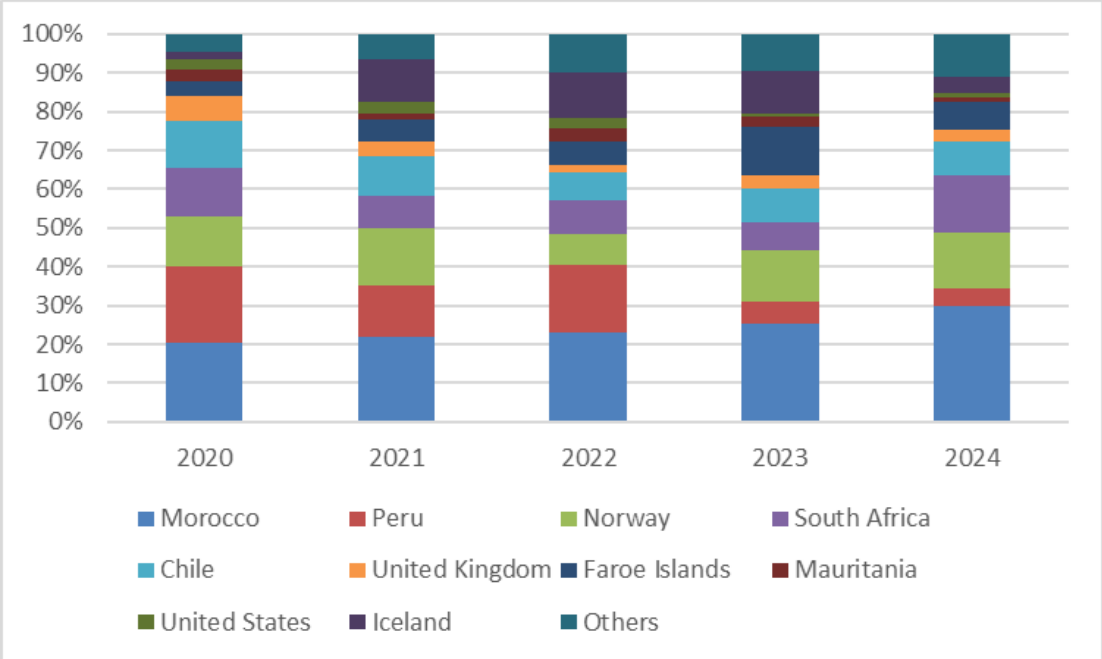
Figure 25 – Main EU fishmeal importers in value (percentages)



Source: EUMOFA (2025)

EU fishmeal imports came from 71 countries in five continents (Figure 26). In 2024, Morocco was the main provider of fishmeal in terms of volume (30%), South Africa (15%), Norway (14%), Chile (9%), and Faroe Islands (7%). Morocco has consistently increased its participation in the EU market in the period 2020 – 2024. Its market share has grown in 38%. Nonetheless, Faroe Islands is the supplier with the greatest growth in its market share (80%). In contrast, **Peru has lost a large part of the EU market share** (-77%). This may be related with fluctuations in resource abundance due to El Niño. Moreover, the Asian market is the main destination of Peruvian exports. Chile, another producer of the region, has also lost participation in the market (-31%). In 2004, Morocco gathered 27% of the market share in terms of value, Norway (19%), South Africa (13%), Chile (10%), and Faroe Islands (8%). Morocco has increased its market share in 80%. Faroe Islands, in turn, has increased it in 117%. Peru has lost its share in -73%. Chile has only seen its share decline in 7%.

Figure 26 – Main international suppliers of fishmeal to the EU in volume (percentages)



Source: EUMOFA (2025)

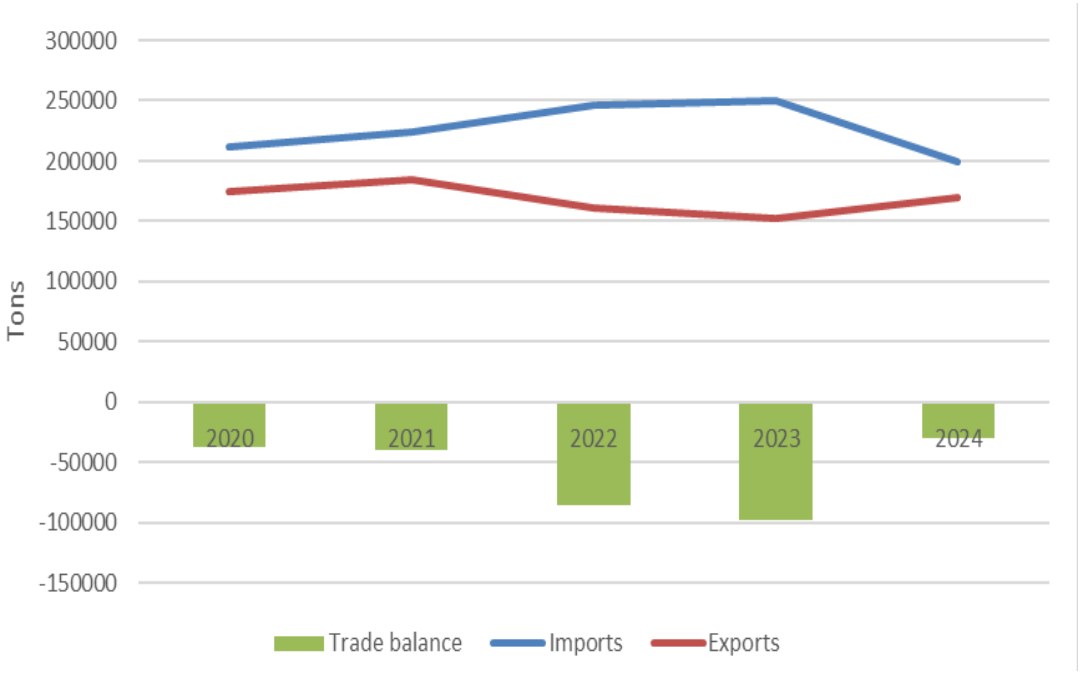
Data on fishmeal production, imports and exports enables us to make some estimates depicting the EU's dependency on fishmeal from international suppliers. The table below shows a gross calculation of the EU's apparent consumption of fishmeal and self-sufficiency of the EU market. Apparent consumption is a proxy for demand and is a metric commonly used in food market studies. Apparent consumption = production + imports – exports. Thus, this is the fishmeal retained in the EU for use as a material in animal feeds. The self-sufficiency rate, in turn, assesses to what extent the EU is self-sufficient on a given food product, in this case fishmeal. It indirectly reflects the level of

dependency on foreign providers. Self-sufficiency is defined as the ratio of regional production to apparent consumption. These gross estimations suggest that **the EU's current level of self-sufficiency is 77%, while dependency on international fishmeal suppliers is moderate**, at around 23% in 2023 (see Table 8 and Figure 27 below). Nevertheless, there appears to be a **downward trend on self-sufficiency**, with the EU becoming progressively reliant on international producers. The reason behind the decrease in self-sufficiency is multifactored but it related to an **increase in apparent consumption not met by an increase in EU production** therefore increasing the reliance on imports to fill gaps.

Table 9 – Estimation of self-sufficiency rate (SSR) of fishmeal in the EU

Year	EU 27 Production (tonnes)	SSR
2014	424,489	84.6%
2015	473,510	94.4%
2016	418,095	87.4%
2017	521,029	102.6%
2018	492,419	86.1%
2019	502,157	84.7%
2020	495,191	89.9%
2021	467,412	89.8%
2022	440,932	80.3%
2023	457,363	77.1%

Figure 27 – EU trade balance of fishmeal (volume, tonnes)



Source: EUMOFA (2025)

Figure 28 – EU trade balance of fishmeal (value, EUR)



Source: EUMOFA (2025)

3.3.2. Marine oils (fish oil, krill oil)

For most commercial aquafeeds used in the production of our target species, only general data on total crude lipid (fat) content is available, with limited information specifically detailing the inclusion rates of fish oil or other marine-derived oils. Nevertheless, available sources, industry reports, and feed formulations allow for a partial characterization of the use of marine oils—primarily fish oil—in feeds for key aquaculture species.

According to EUMOFA estimates (2025), the average annual production of fish oil in the EU during the period 2010–2023 was approximately 143,000 tonnes, with fluctuations ranging from 88,000 tonnes in 2012 to 137,000 tonnes in 2020.

According to data from EFFOP (2024), approximately 74.4% of fish oil produced in Europe is used by the aquaculture sector. Assuming the same ratio for the EU, it can be estimated that **around 106,000 tonnes of fish oil produced in the EU is utilised annually in aquafeed production**.

Eurostat-PRODCOM data (2025) for the production code 10411200 – Fats and oils and their fractions of fish or marine mammals (excluding chemically modified) indicate lower (underestimated) production figures. This discrepancy may be due, in part, to the absence of data from countries such as Ireland, France, the Netherlands, and Germany. Nevertheless, the data for the remaining Member States allows for the identification of specific trends:

- Denmark is the clear leader, with an average annual fish oil production of approximately 66,000 tonnes.
- Spain follows, with an average annual output of around 25,500 tonnes.
- Other contributors include Poland (approximately 3,700 tonnes/year) and Slovakia (approximately 650 tonnes/year).
- Minor production was recorded in Portugal and Finland, each contributing less than 500 tonnes/year on average.

The raw material for fish oil production in Europe largely consists of small pelagic fish species (such as sandeel, sprat, blue whiting, boarfish and herring), alongside trimmings from fish processing industries.

According to Eurostat external trade data (2025), the average annual volume of marine oil imports (under CN code 150420 – Fats and oils of fish and their fractions, whether or not refined [excluding liver oils and chemically modified]) from non-EU countries (Extra-EU) to EU-27 Member States over the past 10 years was approximately 189,000 tonnes. Imports ranged from a minimum of 143,000 tonnes in 2024 to over 210,000 tonnes in peak years such as 2018 and 2020. The top suppliers of fish oil to the EU are Peru, Norway, and Chile (EUMOFA, 2025; OECD/FAO, 2024).

At the same time, EU Member States exported an average of 148,000 tonnes of fish oil annually during the same period. Exports reached a minimum of 128,000 tonnes in 2023, while the highest recorded export volume was 175,000 tonnes in 2020. **The EU's fish oil trade balance remains negative**, with imports consistently exceeding exports. On average, the EU trade deficit in fish oil during the period 2015–2024 was approximately 40,000 tonnes per year.

Based on the data presented above, it can be estimated that **the EU’s self-sufficiency rate for fish oil production in recent years has been approximately 78%, which is a relatively high level**.

Table 10 – Estimation of self-sufficiency rate of fish oil in the EU

Year	EU 27 Production (Tonnes)	SSR
2014	137,800	71.8%
2015	122,280	72.1%
2016	147,746	78.6%
2017	157,148	78.2%
2018	139,599	70.9%
2019	147,629	77.9%
2020	149,641	76.7%
2021	157,987	80.8%
2022	160,137	77.9%
2023	172,268	73.7%

Fish oil has traditionally been the cornerstone lipid source in aquafeeds, particularly for carnivorous and marine fish species, due to its unparalleled content of long-chain omega-3 polyunsaturated fatty acids (n-3 LC-PUFAs), namely eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Oliva-Teles *et al* 2015; Nasopoulou & Zabetakis, 2012; Wu *et al* 2024). These essential fatty acids are critical for optimal fish growth, reproduction, health, and product quality, and are also valued by consumers for their human health benefits (Wu *et al* 2024).

Concerns over sustainability, fluctuating supply, and rising costs of fish oil have necessitated the exploration of alternative marine-derived lipid sources (Oliva-Teles *et al* 2015; Zatti *et al* 2023). While plant oils such as soybean, rapeseed, or palm can partially replace fish oil, they lack EPA and DHA and have limitations related to the nutritional profile and fatty acid deposition in fish tissues, particularly for carnivorous species (Nasopoulou & Zabetakis, 2012; Fan *et al* 2024; Wu *et al* 2024). Krill oil, derived from Antarctic krill (*Euphausia superba*), has emerged as a highly promising marine alternative. Rich in omega-3 fatty acids, phospholipids, astaxanthin, and high-quality proteins, krill oil not only provides essential nutrients but also acts as a natural feed

attractant, enhancing feed intake and efficiency across various species (Kaur *et al* 2022; Torrecillas *et al* 2021; Kolkovski *et al* 2000).

Studies demonstrate consistent improvements in growth performance, FCR and SGR in fish such as European sea bass (*Dicentrarchus labrax*), carp (*Cyprinus carpio*), and salmonids, as well as in Pacific whiteleg shrimp (*Litopenaeus vannamei)* (Năstac *et al* 2023; Torrecillas *et al* 2021; Soares *et al* 2021). Krill oil inclusion also supports liver health, reduces hepatic fat accumulation, and maintains or improves fillet quality and pigmentation in farmed species (Kaur *et al* 2022; Torrecillas *et al* 2021; Storebakken, 1988). Whilst krill are one of the best replacements for marine fish materials from a nutritional perspective, the species is a central prey species in the Southern Ocean food web and **there are concerns that overfishing and the impact of climate change may threaten krill populations** and with it damage the wider ecosystem (Meyer et al. 2025).

There is also growing interest in the use of marine amphipods, a number of amphipod species have been shown to have protein contents up to 40% and high levels of n-3 LC-PUFAs (Jiménez-Prada et al. 2018). These species often occur naturally around fish farms and can be grown using traditionally farmed macroalgae species, research is underway to investigate the potential of incorporating amphipods into IMTA systems (Arcos-Limiñana et al. 2025; Jiménez-Prada et al. 2018; Jiménez-Prada et al. 2021).

3.3.2.1. Use of marine oils in the target species

For **salmon**, fish oil is a critical material, especially in marine grower and broodstock diets. Historically, inclusion levels in salmon feeds vary with the life stage, ranging from 10.4% for small fish to as high as 25.8% in the diets of the larger fish. Historical trends show a significant reduction in fish oil usage: according to Mowi (2024), in 1990, Norwegian salmon diets contained an average of 24% fish oil, but by 2023, this had decreased to 13% in Mowi's commercial formulations, reflecting broader industry efforts to reduce dependence on marine oils.

In **shrimp** diets, fish oil inclusion is generally much lower than in salmon feeds, typically ranging from 3–5% in early post-larval stages (PL1–PL15) to 1–3% in grow-out feeds. This reflects the species' lower requirement for long-chain omega-3 fatty acids compared to marine carnivores.

For **turbo**t, feed formulations focus on total lipid content rather than specific fish oil inclusion. Crude lipid levels vary from 12% in broodstock feeds to 12–22% in grower diets, depending on size and growth stage.

Bluefin tuna diets – so called ‘trash fish’ - are typically high in lipids, with reported crude lipid levels around 17.9%. However, specific data on fish oil

inclusion is variable depending on the species of trash fish - and rarely recorded.

In **European sea bass** feeds, minimum crude lipid levels increase with fish size, ranging from 15% in pre-starter diets (<5 g) to 19% in grower diets (350–500 g), then slightly decreasing for broodstock (17%). Again, detailed information on fish oil inclusion is sparse, though marine oils are generally an important source of essential fatty acids in these diets.

For **sole**, crude fat content ranges between 11% and 14% across different growth stages, with no specific data available on fish oil usage.

Carp is traditionally fed grain-based diets without the inclusion of marine materials, including fish oil. However, in the case of commercial extruded feeds, fish oil was present in 80% of the analysed formulations. While not essential, its use may support specific nutritional goals, particularly in more intensive farming systems. Crude fat levels in carp diets vary with fish size, typically ranging from 7% to 15%.

For **sturgeon**, fish oil was present in 80% of analysed feeds. Crude lipid content varies depending on size category, ranging from 12% to 17% in juvenile diets and stabilizing at 15% for grower feeds. Broodstock diets tend to have a slightly lower crude fat content of around 12%.

Rainbow trout diets also frequently include fish oil, with presence in 90% of the analysed feeds. Crude lipid levels vary considerably, from 9–12% in fry diets (0–0.5 g) to 14–33% in large trout over 1 kg, reflecting the species’ capacity to utilize high-fat diets for growth.

The inclusion levels indicated in this section are summarised in Table 11 below.

Table 11 - Summary of inclusion levels of fish oil/crude lipid indicated for target species

Species	Indicated inclusion levels
Salmon	Small fish diets, fish oil inclusion: 10.4%; as high as 25.8% fish oil inclusion for larger fish diets
Shrimp	Diets for early post-larval stages (PL1-PL15) fish oil inclusion: 3-5%; grow-out diets: 1-3%
Turbot	Broodstock diets, total lipid content: 12%; grow-out diets, total lipid content: 12-22%
Bluefin tuna	Trash fish reported around 17.9% crude lipid content
European sea bass	Pre-starter diets (<5g) 15% crude lipid; up to 19% crude lipid levels in grower diets (350-500g); 17% crude lipid inclusion for broodstock diets
Sole	Crude fat content between 11-14%
Carp	Fish oil present in 80% of commercial feeds; crude fat levels in diets: 7-15%

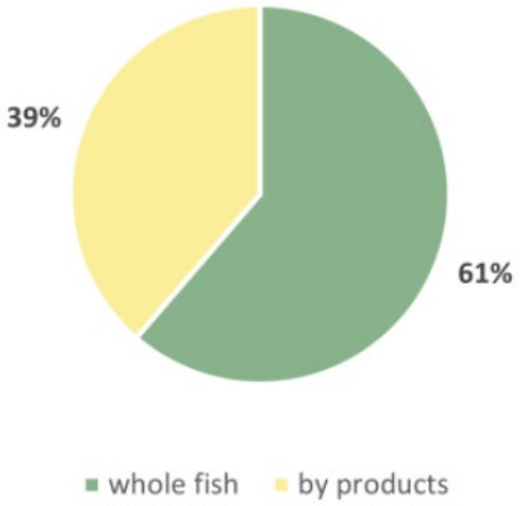
Species	Indicated inclusion levels
Sturgeon	Fish oil present in 80% of commercial feeds; crude fat levels in diets for juveniles: 12-17%; crude lipid content for grower diets: 15%; crude lipid content for broodstock diets: 12%
Rainbow trout	Fish oil present in 80% of commercial feeds; fry diets (0-0.5g): 9-12% crude lipid level; increasing to 14-33% crude lipid content for larger diets

3.3.3. Fishery and aquaculture byproducts

Fishery and aquaculture byproducts are the raw feed materials that remain after the industrial-scale processing of fish for human consumption. After processing, between 50% and 70% of the byproducts are considered ‘‘inedible’’ and typically consist of trimmings (i.e., viscera, heads, skin, bones, and blood). This inedible portion is increasingly being considered as **a practical option to replace the use of fish meal from reduction fisheries** (i.e., wild catch specifically caught for producing fish meal) in aquafeeds. In general, high-quality fish meal produced using whole fish contains 66%–74% crude protein, 8%–11% crude lipids, and <12% ash.

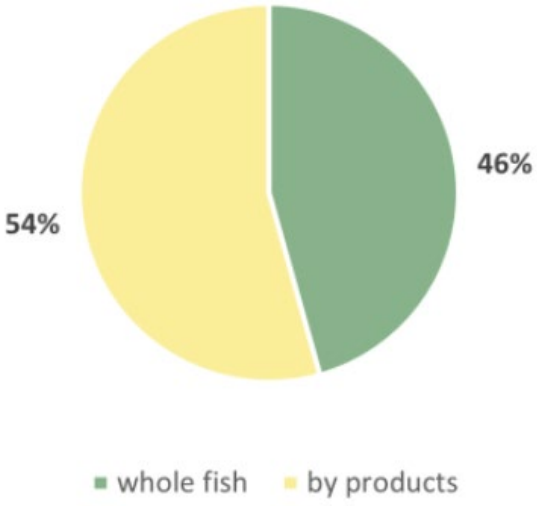
In contrast, fish meal produced from byproducts contains 52%–67% crude protein, 7%–14% crude lipids, and 12%–23% ash. The lower protein content and higher ash content in byproduct fish meals are not unexpected. Although, the different proportions of various byproducts that are used to produce fish meal will therefore also contribute to the nutrient variability of the fish meal made from byproducts. **The lower nutritional profile of byproduct fish meals presents challenges** in the complete replacement of high-quality fish meal. Nevertheless, byproduct fish meal is still a viable alternative to conventional fish meal, and, more importantly, is a more economical and sustainable protein source. The industrial-scale production of fish meal and fish oil from byproducts is challenged by the considerable capital investment and running costs and a constant supply of raw feed materials in large volumes for prolonged economic efficiency. These factors present significant challenges, as the raw materials need to be collected from fish-processing plants located in remote areas or when only small daily quantities are produced.

Figure 29 – Fishmeal production by raw material type (2023)



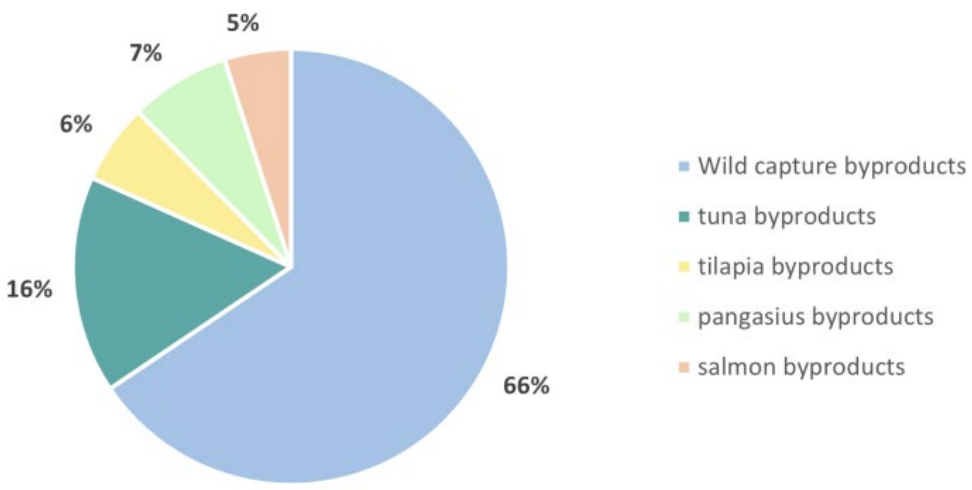
Source: IFFO (2025)

Figure 30 – Fish oil production by raw material type (2023)



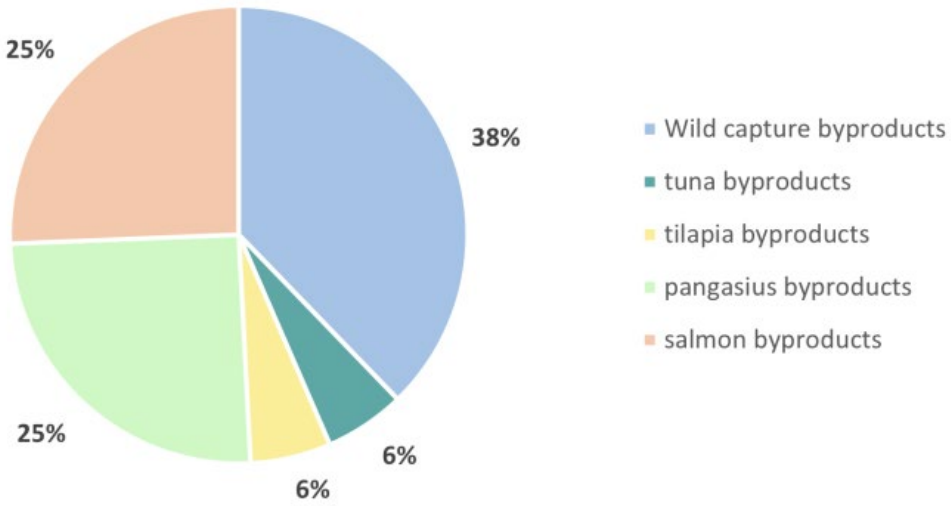
Source: IFFO (2025)

Figure 31 – Sources of by-products used in global fishmeal production (2023)



Source: IFFO (2025)

Figure 32 – Sources of by-products used in global fish oil production (2023)



Source: IFFO (2025)

Table 12 – PESTLE factors affecting marine products and by-products

Cross-cutting factor	Impact on Plant proteins and oils
Political	• Political instability and indecision can undermine agreed stock-sharing arrangements between nations with shared resources (Glencross *et al*., 2024).
Technological	• The suitability of by-products as feed materials is influenced by various factors; however, their widespread adoption necessitates a standardized assessment process to ensure quality and minimize risks (Malcorps *et al*., 2021). • Fish by-products especially when containing viscera deteriorate very rapidly, and it is therefore important that they are preserved as soon as possible after being produced. This is not always possible due for example to inadequate processing facilities or limited volumes making recovery of the by-products non-profitable (Olsen *et al*., 2014).
Legal and Regulatory	• ASC Feed certification covers the responsible sourcing of plant and marine materials with an inclusion above 1% (derived from chapter 3). • The MarinTrust CoC Standard provides assurance that marine materials sold on the global market originate from responsibly sourced raw materials, handled through a verified and traceable supply chain (derived from chapter 3). • The MarinTrust Factory Standard focuses on the responsible manufacturing of marine materials and sourcing of raw materials (derived from chapter 3). • GLOBAL G.A.P’s Compound Feed Manufacturing requires a minimum of 75% of annual purchases of marine materials must come from responsibly managed fisheries (increasing to 100% in 2030) (derived from chapter 3).
Environmental	• The use of relatively "low economic value" fish by-products in aquafeed helps decrease the reliance on pelagic fish as a source of marine materials (Malcorps *et al*., 2021). • Conversely, the disposal of large amounts of marine by-products can cause highly polluting organic matter, which leads to environmental and economic issues (Baek & Cho, 2024).

3.3.4. Plant-based materials

3.3.4.1. Rapeseed

Rapeseed ([55]), due to its low production value, global availability, and balanced amino acid profile, is considered **a promising protein source for aquafeeds** (Higgs *et al*., 1982; Luo *et al*., 2012). Canola is a rapeseed hybrid which was developed through selective plant breeding to contain very low erucic acid (<2%) and low glucosinolates. The most common rapeseed products are cakes/expellers, meals, concentrates, and isolates. Press cakes are a byproduct of oil manufacture, obtained by pressing seeds of rape. Rape seed meal (RSM) is a product of oil manufacture, obtained by extraction and appropriate heat treatment of rape seed cake/expeller (Catalogue of feed materials) ([56]). RSM is known for its moderate protein content (around 39%), good amino acid profile, particularly high in lysine (1.9%) and favourable phosphorus availability (1.2%) (IAFFD, 2025).

Low-erucic acid canola oil (CO) is rich in 18 carbon fatty acids, most notably the monounsaturated fatty acids (MUFAs), 18:1 *n* − 9 (oleic acid) as well as 18:2 *n*− 6 (linoleic acid) and 18:3 *n*− 3 (linolenic acid), and low in saturated fatty acids (SFAs) (Opsahl-Ferstad *et al*., 2003). The potential inclusion of COs into fish feeds, as FO alternates, was previously investigated, particularly for their ready and constant availability, relatively low price. A number of studies have shown that **COs can replace a significant amount of the fish oil** in diets for farmed salmonids without compromising growth or feed efficiency (Bell et al., 2003; Higgs et al., 2006; Turchini et al., 2013). Furthermore, rapeseed oil has been tested in European seabass (Izquierdo et al., 2003; Montero et al., 2005) with encouraging results. However, data from most studies suggested rapeseed oil inclusion is possible for up to 60 % FO replacement in European seabass feeds Wassef et al. (2016).

Studies show **high species-specific variability in terms of maximum inclusion rates**. High dietary inclusion of rapeseed products (including purified concentrates) showed reduced growth performance in various fish species like rainbow trout (*Oncorhynchus mykiss*)(Kaiser et al., 2021a; Kaiser et al., 2021b),Japanese seabass (*Lateolabrax japonicus*) (Cheng et al., 2010) and turbot (*Psetta maxima* L.)(Nagel et al., 2012).

([55]) Defined in point 2.14.1 of the Catalogue of Materials: Commission Regulation (EU) No 68/2013.

([56]) Commission Regulation (EU) No 68/2013 of 16 January 2013 on the Catalogue of feed materials, OJ L 29, 30.1.2013, pp. 1, ELI: http://data.europa.eu/eli/reg/2013/68/oj

3.3.4.2. Soy

Soy and its derivatives—soybean meal and soybean oil—are foundational components of the global feed and food supply chain. In the context of aquaculture, **soybean meal serves as a major plant-based protein source**, while soybean oil is increasingly utilized in both food and industrial applications, including biodiesel (Lee *et al* 2016). The global soybean market is vast and interconnected, shaped by production volumes, trade flows, price dynamics, and policy interventions in major producing countries (Uri *et al,* 1993; Uri *et al* 1994). For the 2024/25 marketing year, global soybean meal production is forecast at 278.1 Mt, marking a 7% increase compared to the previous year (USDA, 2025a). This surge reflects expanded soybean processing capacity and growing demand for protein-rich feeds across livestock and aquaculture sectors (Lee *et al* 2016). China remains the world’s largest producer, accounting for 30% of global output (82.4 Mt), followed by the United States (19%), Brazil (16%), and Argentina (12%) (USDA, 2025a). In contrast, the total soybean production of the EU is around 2.2 Mt, meaning that **approximately 8% of soymeal consumption is covered by domestic soy production** in the EU (Rittler and Pugachov, 2023).

Soybean oil production is projected to reach a record 68.7 Mt in the 2025/26 marketing year, driven by higher soybean crush rates in Argentina, Brazil, the United States, and Ukraine (ERS, 2025). Despite rising output, soybean oil exports are expected to decline slightly as increased domestic demand in major producing countries, particularly for biodiesel production, reduces volumes available for international trade (ERS, 2025). Policy interventions and regional dynamics exert a strong influence on the soybean market. In the United States, agricultural subsidies significantly affect global prices, production patterns, and export competitiveness. Studies have shown that removing U.S. subsidies would lead to a realignment of global trade flows and alter pricing structures (Brandao & Lima, 2006) ([57])

3.3.4.3. Maize/Corn

Global maize production for 2024/25 is expected to decline slightly, contributing to a year-on-year decrease in total global cereal output, now estimated at 2,848 Mt (FAO, 2025b). Lower yields in key producing countries, such as the United States and parts of Europe, are the main drivers of this decline (FAO, 2025b). Maize (or corn) is primarily used in aquafeeds to produce corn gluten meal.

The nutrient requirements of fish, and particularly carnivorous fish species often restrict the available alternative protein resources to a few materials, with high protein content, high digestibility and market availability (Hardy, 1996). Maize

([57]) For further discussion on the use of soy in aquaculture, see Annex 4.

protein feed (synonym corn gluten feed) is a product obtained during the manufacture of maize starch. It is composed of bran and maize solubles. The product may also include broken maize and co-products from oil extraction of maize germs. Other products derived from starch and from the refining or fermentation of starch products may be added. May contain up to 2% sodium and 2% chloride). The word gluten here is inexact; there is no true gluten in corn but simply corn proteins. The expression “corn gluten” is colloquial jargon and is **one of the abundant plant protein sources available for use in aquafeeds** (Nandakumar *et al*., 2017). Corn Gluten Meal (CGM) is an alternative cost-effective source of protein for aquafeeds due to its high protein content of around 60-70% of dry matter, steady supply and competitive price (Glencross et al. 2021). CGM is particularly rich in methionine (1.4%), a critical amino acid often deficient in soybean meal. However, it is relatively low in lysine (1.1%) and phosphorus (0.4%), which may **necessitate supplementation to achieve a balanced diet**. Its low fibre content (2.0%) and high energy density (19.4 MJ/kg) also contribute to its value as an aquafeed material. These values are summarized in Table 96.

CGM has been explored as fish meal substitute in several fish species such as cobia (*Rachycentron canadum*), Japanese seabass (*Lateolabrax japonicus*) and gilthead seabream (*Sparus aurata*), Atlantic salmon (*Salmo salar*), Nile tilapia (*Oreochromis niloticus*), Asian seabass (*Lates calcarifer*), Chinook salmon (*Oncorhynchus tshawytscha*) (Mente *et al*., 2003; Pereira and Oliva-Teles, 2003; El-Ebiary, 2005; Luo *et al*., 2013; Men *et al*., 2014; Nandakumar *et al*., 2017; Doughty *et al*., 2019). Molina-Poveda *et al*. (2015) reports that in general that **CGM can replace 20–40% of dietary FM protein**, but a total replacement of FM by CGM induces a growth reduction of nearly 30%.

3.3.4.4. Wheat

Wheat gluten meal (also vital wheat gluten) is a product from the manufacture of wheat starch and gluten. It consists of bran, from which the germ may have been partially removed. Wheat solubles, broken wheat, and other products derived from starch and from the refining or fermentation of starch products may be added. characterized as a visco-elastic, cohesive, proteinaceous substance.

The crude protein content is approximately 78.2%, making it one of the most concentrated plant protein sources available in the feed industry (Table 111; IAFFD, 2025). Despite its high protein content, wheat gluten meal (WGM) is relatively moderate in essential amino acids like lysine (2.2%) and low phosphorus content (0.2%), requiring supplementation or balancing when used in fish feed formulations (IAFFD, 2025).

The combination of high digestibility and the absence of anti-nutritional factors (ANFs) **enables the replacement of a greater proportion of FM** without

losses in growth performance, in species like sea bass (Tibaldi et al., 2003) and Atlantic salmon (Storebakken et al., 2000). **The main problem is its high price and the contradiction with human consumption.** However, its digestibility may be reduced in carnivorous species, and the low palatability and lysine content can limit its use without amino acid supplementation (Glencross, 2020). Additionally, VWG can serve as a pellet binder in aquafeeds, partially replacing indigestible binders (Storebakken *et al*., 2000). The ability of fish to regulate blood glucose and hydrolyse starch in the intestine varies among species and is generally quite low (Wilson, 1994).

Additionally, WGM has a very high gross energy value (21.0 MJ/kg), which contributes positively to the energy balance of aquafeeds (IAFFD, 2025). On the other hand, its **carbon footprint is among the highest for plant-based proteins**—about 3,300 kg CO_2eq/t due to the extra processing that is required for its production, making it less attractive from an environmental sustainability standpoint compared to soybean or rapeseed meal (IAFFD, 2025).

3.3.4.5. Sunflower meal & oil

Sunflower meal (SFM) is high protein by-product derived from the oil extraction Product of oil manufacture, obtained by extraction and appropriate heat treatment of sunflower seed expeller (Catalogue of Feed Materials) is known to have low levels of anti-nutritional factors, high content of sulphur AA (Olvera-Novoa et al., 2002) and high palatability, making it suitable for aquafeeds (Shchekoldina and Aider, 2014). However, the content of available lysine is poor and the level of digestible energy derived from SFM is low due to the high fibre content (Tacon et al., 1984).

The **substitution of fishmeal with moderate sunflower meal inclusion rates had no adverse effects** in species like common carp (*Cyprinus carpio*) (Rahmdel et al., 2018), gilthead seabream (*Sparus aurata*) (Sánchez Lozano et al., 2007), Atlantic salmon (*Salmo salar*) (Gill et al., 2006) and Nile tilapia (*Oreochromis niloticus*)(Hassaan et al., 2019). However, in the same studies, the feeding groups with high SFM content presented impaired growth performance mainly due to the amino acid imbalance and fibre content.

Sunflower oil, one of the world’s four major edible oils along with soybean oil, rapeseed oil, and cottonseed oil, is widely used in daily food preparation due to its high content of PUFAs, ranging from 85% to 95%.

3.3.4.6. Palm oil

Palm oil is a widely used plant lipid in animal and aquafeed formulations due to its high energy density and oxidative stability, especially in warm climate

applications (IAFFD, 2025). It is rich in polyunsaturated fatty acids (PUFA, 65.7%), mainly in the form of linoleic acid (18:2 n-6, 65.7%), which supports energy metabolism and membrane function in fish (IAFFD, 2025).

Palm oil contains moderate levels of oleic acid (22.4%), palmitic acid (6.3%), and stearic acid (5.0%), which enhance pellet durability and shelf life. However, it lacks omega-3 fatty acids like EPA and DHA (0.0%) and provides only 0.1% linolenic acid (18:3 ω-3), making it **nutritionally insufficient for marine species as a sole lipid source**. (Tocher, 2015; Glencross *et al*., 2020; IAFFD, 2025;).

Although palm oil has nutritional restrictions, its cost-effectiveness and high oxidative stability enable its partial replacement of fish oil in grow-out diets for freshwater omnivores such as tilapia and catfish, which serve as energy supplements. It also contains 1.0% phospholipids, offering minimal emulsification benefits compared to marine oils (IAFFD, 2025).

3.3.4.7. Lupins

Lupin meal is derived from lupin seeds (mainly *Lupinus albus* and *L. angustifolius*) and serves as a plant-based protein source in aquafeeds. It is particularly valued for its moderate crude protein content (approximately 36.3%) and favourable amino acid profile, especially its moderate lysine content (1.8%), which is generally low in other plant proteins like corn gluten meal (IAFFD, 2025).

The primary constraints to lupin meal inclusion in aquafeeds are the presence of non-starch polysaccharides (NSPs) and its low methionine content (0.3%), which can reduce nutrient digestibility in fish. Processing methods such as dehulling, soaking, and enzymatic treatment can reduce fibre content and improve digestibility, especially for carnivorous fish species (Francis et al., 2001; Glencross et al., 2020).

Lupin meal is most suitable for omnivorous and herbivorous species such as tilapia, catfish and common carp, and can be included at moderate levels (10–25%). Its amino acid profile complements other plant materials when used in combination. With a carbon footprint of 1,000 kg CO_2eq/t, **lupin meal is moderately sustainable, especially when sourced locally within the EU** (IAFFD, 2025).

3.3.4.8. Faba beans

Faba bean (*Vicia faba*, L.) is a member of the legume family is widely cultivated in different parts of the world as it grows under a wide range of climatic

conditions (Li et al., 2023b). **Faba beans are rich in protein, carbohydrates and various essential vitamins and minerals**. Due to its high nutritional value, it is widely used in both human and animal diets (Badjona et al., 2023). In aquatic animals, the inclusion of faba beans in has been shown to enhance the crispness and firmness of fish flesh. This effect has been observed across various fish species. In particular, incorporating faba beans into the diet of Nile tilapia significantly improved the firmness and chewiness of their fillets (Tian et al., 2019; Li et al., 2023a; Guo et al., 2024). However, **faba beans contain a variety of antinutritional factors** such as total phenolics, tannins, trypsin inhibitor activity, vicine, phytic acid and genistein (Ferruzzi et al., 2009) that can affect the feed palatability as well as the bioavailability of energy and protein, potentially interfering with certain key performance indicators (Meng et al., 2021).

3.3.4.9. Peas

Advances in processing technology have provided more suitable protein sources for the aquafeed industry such as pea protein concentrate (PPC) which is produced by fine grinding dehulled peas into pea flour, followed by air processing which separates the particles based on differences in size and density (Pereira and Oliva-Teles, 2002). Pea protein concentrate (PPC) is a **good candidate to replace fish meal** with its high protein content (42–70 %), favourable amino acid profile which is similar to that of soybean meal (Øverland et al., 2009), relatively low quantities of anti-nutritional factors (ANF) and good binding properties. PPC has been tested in some marine species, such as gilthead seabream (*Sparus aurata*) (Sánchez-Lozano et al., 2009; Sánchez-Lozano et al., 2011), rainbow trout (*Oncorhynchus mykiss*) (Thiessen et al., 2003) and Atlantic salmon (*Salmo salar*) (Carter and Hauler, 2000; Øverland et al., 2009; Penn et al., 2011) with good growth results obtained below 200 g PPC/kg diet. While in Nile tilapia (*Oreochromis niloticus*) fed diets containing 150 g/kg of PPC or less showed promising results (Schulz *et al*, 2007).

3.3.4.10. Barley

Milled barley is a major component of global beer making, and at the end of the distilling process, an insoluble undegraded part of the barley malt grain, also known as brewers grains or brewer's spent grain (BSG), is obtained as a by-product (Mussatto, 2014). BSG is used as a material in animal feeds, including for aquafeeds. BSG by-product is rich in cellulose, hemicellulose, lignin and proteins cellulose, lignin and proteins is abundantly available globally as only in the EU more than 36 billion litres of beer were produced in 2022 (FAOSTAT, 2025) Brewers dried grains (BDG) accounts for approximately 85% of all residues produced by the brewing industry as 20 kg of BDG is produced per 100 L of beer (Fernandes *et al*, 2021). **The use of BSG as an aquaculture**

feed is increasing (Hassan et al., 2016; Estévez et al., 2021; Nazzaro et al., 2021). The utilization of brewery waste **could diminish fishmeal exploitation and would reduce the carbon footprint** by about 1.79 mega tonnes of CO2e (Gokulakrishnan et al., 2023).

3.3.4.11. Cottonseed meal

Cottonseed meal (CSM) is a plant protein source that is abundant throughout the world, is one such feedstuff generated by the removal of oil from the cottonseed and is **much less expensive per unit of protein than fishmeal and other protein feedstuffs** of animal and plant origin, including soybean meal. is high in protein, and generally less expensive per unit of protein than SBM. However, it contains gossypol, a compound that, at high levels, can be toxic to aquatic animals. Also, CSM is low in some essential amino acids, mainly lysine and sulphur containing amino acids methionine and cystine. **The amount of CSM that can be used in aquatic animal feeds depends on the tolerance of animals to gossypol**, amino acid composition, and the relative cost of CSM compared with other protein sources(Li and Robinson, 2006). However, various processing technologies, including solid state fermentation, methanol extraction, and the use of gossypol-degrading enzymes, have markedly reduced or eliminated the presence of antinutrients (Wang et al., 2020).

Previous studies have revealed that certain levels of CSM did not significantly impair the growth performance of fresh and marine water species such as, European flatfish (*Scophthalmus maximus*) (Bian et al., 2017), grass carp (*Ctenopharyngodon idellus*) (Liu et al., 2016) and largemouth bass (*Micropterus salmoides*) (Liu et al., 2016).

Table 13 – Cross-cutting PESTLE factors affecting plant proteins and oils

Cross-cutting factor	Impact on plant proteins and oils
Political	The Common Agricultural Policy fosters self-sufficiency in EU agricultural production. Russia’s invasion of Ukraine has heightened the urgency of protecting EU agriculture from price volatility and trade disruptions (Antonio, 2023b).
Economic	Increasing prices and competition from other sectors, including human consumption, animal husbandry, and biodiesel production (Gasco *et al*., 2018; van Riel *et al*., 2023). Potentially reducing feed costs, which represent more than 50% of the retail price of the fish (Cavrois-Rogacki *et al*., 2022).
Social	The EFISC-GTP certification focuses on feed/food material safety, enhancing transparency, efficiency, and consumer confidence, with standards for vegetable oil, vegetable proteins, and similar materials (derived from chapter 3). The BAP Feed Mill Standard covers HACCP/food safety, production, quality control, community relations, worker safety, and employee relations. Over 50% of soy and 75% of palm oil must be from certified sources (derived from chapter 3).
Technological	Replacing 50–60% of fish oil with plant oil can achieve similar fish growth rates as using 100% fish oil (Nasopoulou & Zabetakis, 2012), while also enriching the product with omega-6 fatty acids (Zlaugotne et al., 2022). Partial replacement of fishmeal by plant-based materials do not compromise growth and feed efficiency (Cavrois-Rogacki et al., 2022).The impacts of plant oils replacing fish oil could be distinctive among different fish species (Qian et al., 2024). Mixed plant oils are more likely to have more balanced fatty acid profile (Qian et al., 2024).
Legal and Regulatory	Regulation No. 1829/2003, the Genetically Modified Food and Feeds Regulation, is relevant to the use of GM grains and cereals. Approved GM feed products include maize and oilseed rape (derived from chapter 3). Regulation No. 396/2005 ([58]), the Pesticides Residue Regulation, establishes maximum pesticide residue levels in food and feed of plant origin (derived from chapter 3). Directive 2002/32/EC on undesirable substances in feed set maximum limits (MPLs) and action thresholds for harmful substances (heavy metals, mycotoxins, dioxins, PCBs, pesticides, etc.) in animal feed including aquafeed REGULATION (EC) No 767/2009 on the placing on the market and use of feed creates a catalogue of defined feed materials with other materials being introduced following review. Sets rules for marketing, use, labelling, and packaging, ensuring safety for animals, humans, and the environment by requiring clear, truthful info, traceability, and scientific backing for claims.

([58]) *OJ L 70, 16.3.2005*, http://data.europa.eu/eli/reg/2005/396/oj

Cross-cutting factor	Impact on plant proteins and oils
Environmental	Climate volatility and extreme weather have a direct and severe impact on crop yields, which are highly sensitive to environmental factors such as humidity, sunlight, heat, and soil quality (Antonio, 2023). Sustainability concerns over deforestation, land-use displacement, eutrophication, and non-renewable fertilisers (Woodgate *et al*., 2022).

3.3.5. Terrestrial animal products

The use of terrestrial animal products in aquafeeds has gained attention as a strategy to **enhance the sustainability of aquaculture, improve circularity of material use, and maintain essential nutritional requirements**. Terrestrial animal products, such as meat and bone meal, feather and blood meal, hydrolysed proteins as well as fat sources such as tallow, are rich in important nutrients for aquatic organisms (Naylor et al., 2000). Though none of them in isolation can mimic the nutritional profile of fishmeal, when used together formulations can be optimised to provide the necessary combination of nutrients.

There are two main issues that impede their wider use. Firstly, supply – not only in terms of the volumes required, but at a consistent quality (Woodgate et al., 2022). Secondly, there are risks associated with the transmission of diseases and contaminants from terrestrial animals to aquatic species (Glencross et al., 2020). While the latter has been managed with arguably the strictest regulatory framework in the world (Woodgate et al., 2021) there is still a public concern, or the perception among aquafeed manufacturers and the aquaculture industry, that inhibits the widespread use of animal byproducts. This is despite numerous studies that have shown that the strategic incorporation of **terrestrial animal products can improve feed conversion ratios** and overall growth performance in aquaculture species such as salmon and European seabass (Stevens et al., 2018). Furthermore, the use of animal by products valorises a waste product that might otherwise be destined for landfill, thus providing a further incentive for their use.

3.3.5.1. Poultry by-products

Poultry blood meal

Poultry blood meal (BM) is a rendered by-product obtained from poultry slaughterhouses and increasingly considered **a sustainable and economically viable alternative to fishmeal in aquafeeds**. As global aquaculture expands and the cost and availability of marine materials fluctuate, BM offers a promising protein source to support growth performance and reduce environmental impacts.

Poultry blood meal is characterised by its high crude protein content and moderate digestibility. However, **the response of different species to BM varies significantly**. While rainbow trout and tilapia can tolerate relatively high inclusion rates, other species may exhibit reduced digestibility or palatability if BM is used excessively (Salehi et al., 2025). In rainbow trout, the apparent protein digestibility of BM has been reported at approximately 87%, while its nitrogen productive value – an indicator of how effectively ingested nitrogen is

converted into body protein – is lower (23%) but still of significant nutritional relevance (Salehi *et al*., 2023).

Although BM contains essential amino acids, its amino acid profile does not fully match that of fishmeal. **Deficiencies, particularly in isoleucine and methionine, may require supplementation** or blending with other protein sources to ensure optimal growth and health in aquaculture species especially in carnivorous species (Médale & Kaushik, 2009). BM also contributes energy to aquafeeds. Studies on poultry nutrition have shown that blood meal has true metabolizable energy values comparable to those of soybean meal, suggesting its broader applicability across monogastric and aquatic species (López & Gordón, 2013).

Numerous studies support the use of BM, either alone or in combination with other rendered poultry products, as a fishmeal substitute in aquafeeds. In species such as rainbow trout and tilapia, partial or complete replacement of fishmeal with BM has demonstrated no adverse effects on growth, feed conversion, or survival (Macusi *et al*., 2023; Salehi *et al*., 2023; Salehi *et al*., 2025). In some trials, 100% replacement of fishmeal has proven feasible without compromising performance metrics, especially when diets are properly balanced with complementary materials (Macusi *et al*., 2023).

In gilthead seabream *(Sparus aurata)*, diets including poultry by-product meals, such as BM and feather meal, have shown beneficial effects on gut morphology and immune response. When compared to high-plant protein diets, BM-based formulations can reduce intestinal inflammation and support gut health, indicating their functional role in welfare-enhanced aquafeeds (Randazzo *et al*., 2021). Martínez-Llorens et al. (2008) proposed that approximately 5% dietary inclusion is safe and does not adversely affect seabream. However, higher levels may alter fillet sensory characteristics and hinder growth when utilized as haemoglobin.

BM also plays a role in integrated aquaculture systems. In aquaponics, BM-based feeds have been associated with increased total nitrogen in effluents, but with reduced levels of dissolved nutrients compared to traditional fishmeal-based feeds. This alters the nutrient profile available for hydroponic crops and may influence overall system dynamics (Gebauer *et al*., 2023; Shaw *et al*., 2022).

As a by-product of slaughterhouses, **BM contributes to circular economy** objectives by transforming animal waste into valuable feed materials. Its carbon footprint is lower than that of marine-derived materials, supporting the shift toward environmentally sustainable aquaculture systems (Silva-Cardoso *et al*., 2018; Randazzo *et al*., 2021). From an economic perspective, BM is generally less expensive than fishmeal, offering feed formulators an effective cost-

reduction strategy without compromising nutritional quality when properly formulated (Salehi *et al*., 2023; Macusi *et al*., 2023).

Poultry by-product meal

Poultry by-product meal (PBM), excluding blood and feather derivatives, is a rendered product derived from the non-edible portions of poultry carcasses, including viscera, necks, feet, and frames. It is increasingly utilised in aquafeeds due to its **wide availability, favourable cost structure, and relatively high nutritional value**. As the aquaculture sector seeks to reduce dependence on marine-derived materials, PBM emerges as a viable candidate for fishmeal replacement, particularly in diets for carnivorous species such as rainbow trout.

PBM is generally characterized by a **high crude protein content (55–70%),** moderate lipid levels, and a favourable amino acid profile, particularly rich in arginine, leucine, and lysine (Johnson, and C.M. Parsons, 1997; Srour, et al., 2016) and metabolizable energy (Dozier and Dale, 2005). Apparent protein digestibility coefficients range from 73% to 93% in rainbow trout, depending on processing conditions and inclusion rates (Salehi et al., 2023). Despite this favourable digestibility, the amino acid profile of PBM does not completely match that of fishmeal. **Supplementation with specific amino acids – particularly methionine and lysine – may be necessary** to achieve optimal growth and nutrient utilisation in farmed fish (Bhargava & O'Neil, 1975; Salehi et al. 2023).

PBM also contributes a considerable amount of metabolizable energy, making it suitable not only as a protein source but also as an energy contributor in compounded feeds (Bhargava & O'Neil, 1975). However, the nutrient composition can vary by processing method and batch, necessitating quality control for consistent feed formulation.

Poultry by-product meal has demonstrated effectiveness as a fishmeal substitute in practical diets for rainbow trout. Diets including up to 22% PBM – when combined with other locally available protein sources – have shown comparable growth performance to fishmeal-based control diets (Salehi et al. 2023). Moreover, in some trials on rainbow trout, PBM, along with other materials, has entirely replaced fishmeal without significant adverse effects on growth, feed efficiency, or fish health, provided the formulation is balanced with limiting amino acids (Salehi et al. 2023; Macusi *et al*., 2023).

In addition to its nutritional merits, **PBM offers sustainability advantages**. Its use reduces the reliance on marine resources, particularly small pelagic fish stocks used in fishmeal production, thus contributing to a more circular and environmentally conscious aquaculture industry (Macusi *et al*., 2023).

The main benefits of PBM include its high protein content, digestibility, and lower cost compared to fishmeal.

However, several limitations persist:

- Its amino acid composition may require strategic supplementation for optimal utilisation in aquafeeds.
- Nutritional quality can vary significantly depending on raw materials and rendering conditions.
- Palatability issues may occur in some species at higher inclusion levels, although rainbow trout generally exhibit good acceptance.

Maintaining consistency in the nutritional quality of PBM remains a priority. **Variability in raw material composition**, rendering temperature, and particle size can affect digestibility and feed intake. Thus, formulation strategies must consider batch-specific nutrient profiles to ensure predictable performance (Salehi et al. 2023). Current research focuses on improving processing technologies, amino acid balancing, and defining species-specific inclusion thresholds for optimal performance (Bhargava & O'Neil, 1975; Salehi et al. 2023).

Hydrolysed feather meal

Hydrolysed feather meal (HFM), a protein-rich by-product of the poultry processing industry, is gaining increasing attention in aquafeed formulation due to its **high availability, cost-effectiveness, and sustainability potential**. Produced primarily from poultry feathers via hydrolysis, fermentation, or enzymatic treatment, feather meal provides an opportunity to recycle animal waste into a valuable feed material. It is particularly common in trout diets and is widely applied in the aquafeed industry. Its affordability compared to fish meal and bone meal makes it a cost-effective choice for feed manufacturers (Shahabuddin *et al*., 2024).

Hydrolysed feather meal (HFM) has **extremely high crude protein levels**, usually between 78% and 87%, depending on processing. It’s also rich in sulphur amino acids like cystine and cysteine, which are abundant in feathers’ keratin protein (Shahabuddin *et al*., 2024; Handayani *et al*., 2024; Moritz & Latshaw, 2001). This high protein content makes it attractive as a partial fish meal substitute. However, HFM contain low levels of essential amino acids, particularly methionine, lysine, and histidine. Consequently, **supplementation may be necessary to fulfil the nutritional requirements** of farmed aquaculture species (Lillie *et al*., 1956; Handayani *et al*., 2024).

Fat content in HFM is generally low, around 5%, contributing to its stable storage characteristics (Shahabuddin *et al*., 2024). Digestibility is highly dependent on processing. Raw feather meal is poorly digested by fish, but hydrolytic treatment significantly enhances amino acid availability. Advanced methods such as fermentation and enzymatic treatment further improve

digestibility and protein utilisation (Salehizadeh *et al*., 2025; Handayani *et al*., 2024).

Studies have shown that HFM can partially replace 20–30% of fish meal or animal protein in aquafeeds without adversely affecting growth performance or feed conversion, provided the diet is supplemented with limiting amino acids (Cao *et al*., 2020; Fornari *et al*., 2023). For example, in juvenile turbot (*Scophthalmus maximus*) and channel catfish (*Ictalurus punctatus*), enzyme-treated feather meal has been shown to support normal growth and nutrient utilisation.

While effective in many species, responses vary. At high inclusion rates, some fish may exhibit reduced feed palatability or diminished growth performance due to amino acid imbalances or poor digestibility (Fornari *et al*., 2023). Therefore, careful diet formulation is essential when incorporating HFM into aquafeeds.

The nutritional value of HFM is heavily influenced by the processing method. Controlled hydrolysis using steam or acid enhances the availability of sulphur-containing amino acids, such as cysteine, and minimises protein degradation (Moritz & Latshaw, 2001). Fermentation using probiotics or enzymatic treatments can further improve the amino acid profile and digestibility, making feather meal more nutritionally suitable for aquaculture species (Dawood *et al,* 2018; Salehizadeh *et al*., 2025).

The quality and nutritional consistency of HFM can vary between producers and processing batches. Monitoring these parameters is crucial for reliable feed performance outcomes. However, feeds containing HFM may alter effluent nutrient composition in recirculating aquaculture systems (RAS) or integrated aquaponics setups. Therefore, nutrient efflux and water quality should be carefully managed in such systems (Gebauer *et al*., 2023). Feathers typically account for 3% to 7% of a live chicken's weight.

3.3.5.2. Porcine by-products

Porcine meat and bone meal

Porcine meat and bone meal (PMBM) are increasingly utilised as alternative protein sources in aquafeeds due to the rising cost and limited availability of fishmeal. Derived from the rendering of porcine tissues such as meat scraps, bones, organs, these materials are processed under controlled conditions to ensure **safety and high nutritional value**. Their use supports the circular economy and contributes to **more sustainable aquaculture** practices (Woodgate *et al*., 2022).

Porcine by-products are characterized by a **high crude protein content**, typically ranging from 45 to 55%, depending on the processing method (IAFFD, 2025). However, the porcine blood meal may exceed 90% crude protein. These by-products also contain essential amino acids, minerals, and digestible lipids. Apparent protein digestibility can reach 95.9% in some species, placing PMBM on par with or even surpassing traditional fishmeal in nutrient absorption. (Wang *et al*., 2012). These meals are also rich in calcium and phosphorus, though high inclusion levels may lead to increased fat deposition in fillets or reduced processing yields (Li *et al*., 2018). Methionine and lysine levels, although substantial, may become limiting at higher inclusion rates, requiring dietary balancing (Qiu & Davis, 2018).

PMBM have been successfully incorporated into the diets of a wide range of aquaculture species, demonstrating both **nutritional and functional benefits**. In shrimp nutrition, for example, porcine meal can be included at moderate levels (up to 6%) in low-fishmeal diets without compromising growth performance or protein retention (Qiu & Davis, 2018; Hernández et al., 2008). In gilthead sea bream, porcine protein hydrolysates and spray-dried porcine plasma have provided benefits beyond basic nutrition, including enhanced immune responses, improved gut health, and greater feed efficiency, particularly under reduced-fishmeal conditions (Gisbert et al., 2021; Fernández-Alacid et al., 2022; Vallejos-Vidal et al., 2022).

Overall, PMBM represent a **cost-effective and highly digestible protein source**, with the additional advantage of promoting health and immunity. Their main benefits include reduced feed costs relative to fishmeal (Li et al., 2018), high nutrient digestibility and amino acid availability (Wang et al., 2012), and functional effects on immune competence and stress tolerance (Gisbert et al., 2021; Fernández-Alacid et al., 2022). Nonetheless, their use **requires careful formulation to avoid potential drawbacks**. Excessive inclusion levels (>30–40%) have been associated with reduced growth and impaired gut health (Hernández et al., 2008; Huang et al., 2022). Moreover, due to an imbalanced amino acid profile, diets containing PMBM may require supplementation with methionine and lysine (Wang et al., 2012). At high dietary levels, these materials can also alter product quality, increasing fillet lipid deposition and reducing processing yield (Li et al., 2018).

Porcine blood-derived products: plasma and haemoglobin

Porcine blood-derived products, particularly spray-dried plasma and haemoglobin powder, have garnered growing attention in aquaculture due to their high nutritional value, functional properties, and potential to enhance growth performance and immunity in fish. These by-products are processed under controlled conditions from animal blood collected during slaughter and represent a **sustainable, safe, and highly digestible alternative to fishmeal**.

Spray-dried porcine plasma contains 75–90% crude protein, low moisture content (<4.3%), and a broad spectrum of essential minerals, including sodium, potassium, phosphorus, iron, zinc, and molybdenum. Its amino acid profile closely resembles that of egg protein, although it may be limiting in isoleucine under certain dietary conditions (Vallejos-Vidal *et al*., 2022; Fernández-Alacid *et al*., 2022). The product is particularly rich in immunoglobulins and bioactive peptides that can exert systemic and gut-level immunomodulatory effects (Gisbert *et al*., 2021).

Porcine haemoglobin powder typically contains over 80% crude protein and serves as a concentrated source of heme iron. Hydrolysed haemoglobin exhibits notable antioxidant capacity and iron-chelating properties, which are linked to the composition and molecular weight of resulting peptides (Woodgate *et al*., 2022). This makes it a functional material, particularly relevant in fish species prone to oxidative stress or anaemia.

Beyond nutrition, porcine plasma and haemoglobin contribute to improved physical properties of aquafeeds, including enhanced water-holding capacity, pellet texture, and emulsification. These features support better feed stability and ingestion. However, the metallic taste and dark red colour associated with haemoglobin may require decolourisation or masking to ensure palatability in fish diets (Woodgate *et al*., 2022).

The drying method and pH during processing influence the functional quality and amino acid bioavailability, particularly for lysine, which is prone to degradation (Vallejos-Vidal *et al*., 2022). Therefore, **standardised production protocols are essential to preserve nutritional integrity** and ensure repeatability across feed batches.

Spray-dried porcine plasma and its hydrolysates have demonstrated positive effects on growth, feed efficiency, and immune function in species such as gilthead seabream *(Sparus aurata)*. When included in low-fishmeal diets, plasma can promote the expression of immune-related genes, enhance mucosal antimicrobial activity, and improve intestinal morphology (Gisbert *et al*., 2021; Fernández-Alacid *et al*., 2022; Vallejos-Vidal *et al*., 2022).

Porcine haemoglobin powder has also shown efficacy in partially or fully replacing fishmeal in various fish diets without compromising growth or product quality. It provides a cost-effective solution, especially in formulations with reduced marine-derived materials (Hernández *et al*., 2008).

Porcine plasma and haemoglobin are considered safe and functional feed materials. Their digestibility, protein quality, and immunological benefits make them suitable for a wide range of aquaculture species. Nonetheless, careful attention to processing conditions is required to minimise protein denaturation and maximise nutrient retention.

3.3.5.3. Porcine and poultry fat by-products

Rendered animal fats – including poultry fat, pork lard, and other eligible Category 3 materials of non-ruminant origin – are also classified as animal by-products under the animal by-product regulation ([59]) and **may be legally incorporated into animal feeds under strictly defined sanitary and regulatory conditions**. When sourced from approved non-ruminant sources and processed in accordance with EU standards, these fats serve as safe and effective energy sources in aquafeed formulations.

Fats derived from ruminants (e.g., beef tallow) are generally prohibited in aquafeeds within the EU due to TSE regulations, unless processed and handled under specific exemptions outlined in Regulation (EC) No 999/2001 ([60]) and related amendments.

Animal fats are increasingly utilised in aquafeed formulations as alternative sources of energy and nutrients, aiming to improve feed cost-efficiency and reduce dependence on marine-derived materials such as fish oil and fish meal. Their inclusion supports circular economy principles – transforming slaughterhouse by-products into valuable feed resources – and **aligns with sustainability goals by reducing waste.** Moreover, their use is subject to strict regulatory controls within the European Union, ensuring both traceability and safety.

Common rendered fats such as poultry fat, pork lard, and – under certain legal conditions – beef tallow are valuable lipid sources due to their high caloric density and relatively good digestibility, especially when diets are nutritionally-balanced. These fats are composed primarily of saturated and monounsaturated fatty acids (Trushenski & Lochmann, 2009; Bureau *et al*., 2002). However, they contain negligible amounts of long-chain omega-3 polyunsaturated fatty acids (LC-PUFA) – such as EPA and DHA – which are essential for fish health, growth performance, and the nutritional quality of aquaculture products for human consumption (Colombo *et al*., 2020; Glencross, 2009).

When properly formulated to meet species-specific fatty acid requirements, animal fats can replace up to 30–40% of total dietary lipids in many cultured species without adverse effects on growth, feed conversion efficiency, or fillet quality (Ruiz *et al*., 2024; Bureau *et al*., 2002). Their use also offers **economic advantages**, reducing exposure to the price volatility associated with marine lipids. For example, rendered fats are generally more price-stable and cost-

([59]) Regulation No 1069/2009

([60]) *OJ L 147, 31.5.2001*, ELI: http://data.europa.eu/eli/reg/2001/999/oj

effective than fish oil, contributing to improved formulation resilience under changing market conditions.

Experimental trials demonstrate promising outcomes. Terrestrial fats have been successfully included at levels of 8% in salmon (Emery *et al*., 2014) and 6% in gilthead seabream (Pérez *et al*., 2014), with no detrimental effects on performance or product quality when essential fatty acids are adequately supplied.

However, the **industry remains cautious due to consumer perceptions and regulatory complexity**. There are persistent concerns – often unsupported by empirical data – that animal fats could alter the taste of farmed fish (Bureau *et al*., 2002; Gause & Trushenski, 2013; Liu *et al*., 2004). Past food safety crises such as bovine spongiform encephalopathy (BSE) have further contributed to scepticism in certain markets (Shurson *et al*., 2023). Although more stable than many plant oils, rendered animal fats can become rancid if improperly handled, leading to reduced palatability and potential health risks. Antioxidants are commonly added to prevent oxidation (Xie *et al*., 2020; Babalola & Apata, 2011).

3.3.6. Insects

The European Union approved processed animal protein from insects (i.e., insect meals) to be used in aquafeed in Regulation (EU) 2017/893 ([61]) from July 2017. **There are currently nine insect species approved for use** (when raised with feed-grade substrates),the black soldier fly (*Hermetia illucens*), the common housefly (*Musca domestica*), and the yellow mealworm (*Tenebrio molitor*), with research focusing on these three, other approved species were: Lesser Mealworm (*Alphitobius diaperinus*), House Cricket (*Acheta domesticus*), Banded Cricket (Gryll*odes sigillatus*), Field Cricket (*Gryllus assimilis*). The list was later expanded to include the silkworm (*Bombyx mori*) through Commission Regulation (EU) 2021/1925 ([62]). While not on the initial list, *Locusta migratoria* was included in subsequent amendments and is now a recognized source. Whilst insects are allowed there are requirements in the name of safety, as with other products those placing insect products on the market must comply with

([61]) Commission Regulation (EU) 2017/893 of 24 May 2017 amending Annexes I and IV to Regulation (EC) No 999/2001 of the European Parliament and of the Council and Annexes X, XIV and XV to Commission Regulation (EU) No 142/2011 as regards the provisions on processed animal protein

([62]) Commission Regulation (EU) 2021/1925 of 5 November 2021 amending certain Annexes to Regulation (EU) No 142/2011 as regards the requirements for placing on the market of certain insect products and the adaptation of a containment method

Regulation (EC) No 767/2009 ([63]). Directive 2002/32/EC ([64]) and Regulation (EC) No 396/2015 ([65]) set limits for the amount of undesirable substances and pesticide residues allowable respectively and being classed as farm animals there are strict requirements under Regulation (EC) No 1069/2009 on animal by-products on the substrate that can be fed to insects.

The crude protein level in most insects ranges from 40% to 63%, however, defatted insect meal can contain up to 83% crude protein. The amino acid profiles are taxon dependent and vary with species, with the Diptera group (true flies) demonstrating similar profiles to that of fish meal. The crude lipid content of insects ranges from 8.5% to 36%, while the fatty acids profiles are variable and dependent on developmental stage and the substrates used as a nutrient source. Insects contain negligible amounts of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), lower levels of omega-3, and higher levels of omega-6 fatty acids compared with fish meal. Lipid quality can be manipulated by the substrates used to raise the insects, and it is possible to enrich the EPA and DHA content by feeding insects with fish offal, however, this might be economically less advantageous than feeding fish byproducts directly to fish. Vitamin and mineral content are also highly dependent on substrate type. Insects are low in carbohydrates (<20%), which are mostly in the form of chitin, a polymer of glucosamine generally considered as anti-nutritional, that fish cannot digest. **Most studies that replace fish meal with insect meal recommended partial replacement** (reviewed by Tran *et al* 2015 and Nogales-Mérida *et al* 2019). However, **an increasing number of studies are reporting that a 100% replacement of fish meal can be successful**, even for carnivorous fish such as Atlantic salmon (Belghit *et al*., 2019) and rainbow trout (Rema *et al*., 2019).

Challenges of incorporating insect meal into aquaculture feeds include the variable and sometimes less ideal nutritional profiles. Moreover, insect meal is currently not seen as a price-competitive raw material for aquafeeds (Hua *et al* 2019). This is partly a scale issue with larger EU producers now capable of producing larvae at €1/kg (€3/kg for insect meal) (IPIFF, Personal

([63]) Regulation (EC) No 767/2009 of the European Parliament and of the Council of 13 July 2009 on the placing on the market and use of feed, amending European Parliament and Council Regulation (EC) No 1831/2003 and repealing Council Directive 79/373/EEC, Commission Directive 80/511/EEC, Council Directives 82/471/EEC, 83/228/EEC, 93/74/EEC, 93/113/EC and 96/25/EC and Commission Decision 2004/217/EC

([64]) Directive 2002/32/EC of the European Parliament and of the Council of 7 May 2002 on undesirable substances in animal feed - Council statement

([65]) Regulation (EC) No 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC

Communication) but price-competitiveness is also restricted due to subsidies for fishmeal production globally (Schuhbauer et al. 2020).

The nutritive value of insects can be enhanced by combining insect meals with complementary nutritional profiles or by manipulating the substrate used as a nutrient source to improve fatty acid content, digestibility, and even palatability (Nogales-Mérida *et al* 2019).

Insect meals and oils have emerged as **a promising alternative protein source in aquaculture feeds**. Insects are considered a viable option due to their rapid growth, high feed conversion efficiency, relatively good nutritional profile with a low carbon footprint, and ability to be reared on organic waste streams – thereby, contributing to waste reduction and a more circular economy.

Nutritional profiles of insect meals are comparable to fish meal and can be manipulated with the waste product fed (Hua *et al*., 2019; Makkar *et al*., 2014) – due to the laws of thermodynamics it is more efficient and therefore economically advantageous to feed materials directly to fish rather than to insects first though only in cases where this is an option nutritionally. **Insect meals typically have a high protein content**, often ranging from 45% to over 60% on a dry matter basis, similar to fishmeal's protein content (around 65%) (Nogales-Mérida et al., 2018). Their amino acid profile is also very good, with a high concentration of essential amino acids required for fish growth. However, some species, like black soldier fly larvae, may have slightly lower levels of lysine and methionine, which can be supplemented (Alfiko et al., 2022).

The fat content of insect meals can be highly variable depending on the species and processing. For example, black soldier fly larvae are rich in lipids, especially saturated fatty acids like lauric acid. This can be a benefit for energy, but it can make their fatty acid profile different from fishmeal, which is rich in omega-3 fatty acids like EPA and DHA (Alfiko et al., 2022).

Insect meals are rich in essential minerals such as calcium, phosphorus, iron, and zinc. The mineral content of the final product can be influenced by the substrate they are raised on (Alfiko et al., 2022).

EU production of insects currently sits around 40-60 thousand tonnes (IPIFF, Personal Communication), and the EU is seen as a pioneer in these areas with more than 40% of total scientific publications of the last decade, but as production in regions like Asia scales fast the EU risks failing to capitalise on this initial lead. Stakeholders within the EU insect production sector believe that the potential of insects to replace marine materials within the EU can be realised if support in the form of incentive mechanisms, investment in R&D and scaling production, and authorizing the use of alternative feed stocks (IPFF, 2026).

Table 14 – PESTLE analysis insect meals and oils

Cross-cutting factor	Impact on insect meals and oils
Political	The 2021 “Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030” stressed the importance of reducing the reliance of feed producers on fish meal and fish oil taken from wild stocks and encouraging the use of alternative protein materials such as algae or insects or the waste from other industries (derived from chapter 2 (section 2.2.1).
Economic	Important cost factors include the raw substrate delivery, building, and inventory (Leipertz *et al*., 2024). For insect farms, differences in sale prices depend heavily on the geographical market, the type of market (feed or food), and the quantity sold. The main operational costs are feed and labour, with feed costs varying significantly both within and between insect species (Niyonsaba *et al*, 2021).
Social	Job creation in the insect production sector; however, there are potential risks such as allergies for employees and possible disturbances to nearby neighbourhoods (Macombe *et al*., 2019). Consumers have a positive attitude toward insect meal as feed, purchasing and eating farmed fish raised on such diets, Interest is influenced by socioeconomic factors, knowledge and the importance placed on origin and certification (Mancuso *et al*., 2016).
Technological	Dietary inclusion supported the growth of fed organisms at levels comparable to a fishmeal-based diet, within a plausible range of 13,1% to 50,3% (Tran *et al*., 2022). Dietary inclusion levels of black soldier fly meal above 29% (±3%) reduced fish growth performance, whereas yellow mealworm was well tolerated (Hua, 2021).
Legal and Regulatory	Regulation No, 1143/2014, the Invasive Alien Species Regulation ([16]), sets out rules to prevent, minimise and mitigate the adverse impact on biodiversity of the introduction and spread within the EU, both intentional and unintentional, of invasive alien species, which is potentially relevant in the context of the import and use of non-endemic insect species for use as aquafeed material (derived from chapter 3). Commission Regulation No, 2017/893, the Processed Animal Protein Regulation ([19]), is particularly relevant as regards the use of insects in aquafeed (derived from chapter 3). The Processed Animal Protein Regulation (authorises the feeding of seven insect species to aquaculture animals with a further two species added through subordinate legislation in 2021 ([66]).

([66]) Commission Regulation (EU) 2021/1925 of 5 November 2021 amending certain Annexes to Regulation (EU) No 142/2011 as regards the requirements for placing on the market of certain insect products and the adaptation of a containment method (OJ L 393, 8.11.2021, p. 4).

Cross-cutting factor	Impact on insect meals and oils
Environmental	From a life cycle assessment perspective, insect meal particularly from *T. molitor* and *M. domestica* potentially reduce environmental impacts of aquafeeds related to land use, but associate with an increase in energy use and carbon footprint (Quang Tran *et al*., 2022). The use of renewable energy and sustainable feeds are a key characteristic in the GHG emissions from insect production (DEFRA, 2023., Francis et al. 2025) and there is evidence that when raised in optimally sustainable conditions insects can be a viable materials for aquafeeds (Francis et al. 2025). Activists may oppose the biorefinery on environmental or animal welfare grounds, citing concerns about agricultural land and water preservation, or objecting to industrial-scale insect production (Macombe *et al*., 2019).

3.3.7. Microbial biomass

The microbial biomass produced by fermentation using various microorganisms, also known as ‘‘microbial protein’’ or ‘‘single-cell protein,’’ is **a promising substitute for animal- or plant-derived materials for aquafeeds**. Among the highly diversified group of microorganisms, bacteria, yeasts, and microalgae are generally regarded as having the highest potential for aquafeeds. Bacteria and yeasts have a relatively high protein content (50%–65% and 45%–55%, respectively), with amino acid profiles that are comparable with fish meal and can potentially be used as either functional feed additives or as alternative raw materials. To achieve this potential **there should be a focus on improving the scale of production**, which will ensure the process chain is environmentally sustainable and reduce the cost of production. Their suitability and inclusion rates will also need to be evaluated at the species level, with a focus on their digestibility and the bioavailability of nutrients contained within the microbial biomass.

Single Cell Protein (SCP) products typically using renewable feedstocks and provide a readily available protein-rich microbial biomass. While SCP is not a new concept, having been used for human and animal nutrition since the 1960s, biotechnological advances have enabled more efficient and cost-effective production processes, which make them more attractive as a commercial protein source (Sharif *et al*., 2021). The effectiveness of SCP inclusion in aquafeeds is dependent on the type of SCP and there are limitations to inclusion rates with too high inclusion having adverse effects on animals (EFSA, 2017). Digestibility and the cost of production are also limitations, and these are discussed in more detail below.

3.3.7.1. Yeast

In aquaculture nutrition, yeast—particularly residual biomass from *Saccharomyces cerevisiae* and other species used in fermentation processes—is widely studied and utilized as **an alternative protein source and feed material**. Commonly known as baker’s or brewer’s yeast, *S. cerevisiae* is one of the oldest and most widely used microorganisms in food and beverage production, including bread, beer, and wine. Whether applied as live yeast, inactive dried yeast, or whole-cell biomass, it is not considered an emerging material but rather **a traditional component in various food and feed applications** ([67]).

([67]) Yeast derivatives, such as yeast extracts, β-glucans, and mannan oligosaccharides, are commonly used in small amounts as feed functional additives to improve health and

Yeast biomass (in the form of whole cells, dried) **can partially replace fishmeal** or soybean meal. It’s valued for its protein content (40–55% crude protein), B-vitamins, nucleotides and amino acids. It can improve palatability and supply nutrients when conventional protein sources are scarce or expensive.

Fungal proteins are gaining attention as a sustainable alternative to traditional protein sources, such as fishmeal, in aquafeeds. Derived from several species of fungi, these proteins are rich in essential amino acids (particularly some, such as lysine, which is sometimes deficient in plant-based proteins), making them a valuable material for aquaculture diets (Onomy & Okuthe, 2024). Additionally, fungal proteins can be produced using various substrates, including agricultural by-products, which **contributes to waste reduction and resource efficiency** in aquaculture (Makkar *et al*., 2016).

Despite their nutritional advantages, the use of fungal proteins in aquafeeds is still developing, and **several challenges remain**. The digestibility of fungal proteins can vary depending on the species and processing methods used, with some fungi containing cell wall components that may hinder nutrient absorption (Sultana *et al*., 2024). Research is ongoing to improve the digestibility of fungal protein sources through various processing techniques, such as fermentation and enzymatic treatments.

Aquatic species exhibit varying degrees of tolerance to fungal proteins. Many studies have shown positive growth performance in fish when diets are supplemented with fungal protein sources. Replacement of fishmeal has been achieved at levels of 50% in European seabass (Oliva-Teles and Goncalves, 2001), 20% in gilthead seabream (Fronte *et al*., 2019), 40% in rainbow trout (Vidakovic *et al*., 2020) and 18-24% in whiteleg shrimp (Guo *et al*., 2019).

3.3.7.2. Fungal proteins

Fungal protein refers to **protein-rich biomass derived from filamentous fungi** (not yeasts). Commercial examples include the following species: *Fusarium venenatum*, *Aspergillus oryzae*, *Rhizopus* spp, *Mortierella alpina* (omega-3 production), *Trichoderma* spp. Fungal protein refers to protein-rich biomass derived from filamentous fungi (branched multicellular organisms) rather than yeasts. They can be cultured on organic-rich waste and by-products which, in turn, affect the nutritional composition of the fungus (Table 15), though they are **typically high in protein**, immunostimulants (such as beta-glucans) and pigments.

performance, serving as immunostimulants, prebiotics, or enhancers of gut health. For this reason, they have also been included in the “zootechnical additives” section later in the report.

Table 15 – Typical protein of fungal species

Fungal Strain	Substrate	Protein Content (% w/w Dry Weight)
Aspergillus oryzae	Palm oil waste	39
Rhizopus oligosporus	Starch processing wastewater	46
Rhizopus sp.	Spent sulphite liquor	50–60
Mucor circinelloides	Corn ethanol stillage	30.4
Pythium irregulare	Corn ethanol stillage	28
Rhizopus, Mucor, Rhizomucor	Isolated from Tempe	47–63
Mucor indicus	Spent sulphite liquor	30–50
Rizhopus oryzae	Vinasse	49.7
Neurospora intermedia	Thin stillage	56
Aspergillus oryzae		48
Rhizopus sp.		55
Rhizopus oligosporus	Corn ethanol stillage	43
Aspergillus oryzae	Stillage	43
Rhizopus oligosporus	Wheat bran	40
Neurospora intermedia	Dairy waste	40
Neurospora intermedia	Lignocellulose	50

Source: Karimi et al. (2018).

3.3.7.3. Bacteria

Bacterial protein is **emerging as an innovative and sustainable alternative** to traditional protein sources in aquafeeds, derived from over 20 species of bacteria, particularly those that can utilize organic waste and by-products, bacterial protein offers a high-quality protein source that is rich in essential amino acids (Makkar *et al*., 2016).

One of the significant advantages of bacterial protein is its **notable protein content**, which can reach up to 80% or more on a dry weight basis, higher than other SCP sources (Bratosin *et al*., 2021). Cultures are also characterized by low density, small cell size and the capacity to easily multiply (within an interval of 20–120 min), characteristics that can lead to a **substantially lower environmental footprint** compared to traditional protein sources (Pander *et al*., 2020). However, bacterial SCP also contains a high proportion of nucleic acids, particularly RNA, which can be as high as 20% (Ellahi and Firdous, 2023). This requires processing steps to lower nucleic acid content before use in aqua diets, while bacterial SCP has a favourable amino acid profile, it tends to lack sulphur-containing amino acids. Additionally, it is important to consider the potential production of endotoxins by certain types of Gram-positive bacteria during SCP production.

Nederlof et al. (2023) observed positive outcomes in terms of growth and phosphorus retention in whiteleg shrimp fed 15% bacterial SCP. However, they emphasize that, like other SCPs, the quality of the final product is significantly influenced by processing conditions. Other inclusion levels include 55% replacement of fishmeal in Atlantic salmon (Tlusty *et al*., 2017). However, other studies have found decreased nutrient digestibility with high inclusion of bacterial SCP (Aas *et al*., 2006).

3.3.8. Microalgae

Schizochytrium sp. (DHA source), Nannochloropsis sp. (EPA and protein source), and Chlorella sp. (protein source) are particularly suitable microalgae candidates to produce algae oil for aquafeed applications. Microchloropsis gaditana is also a promising species, valued for its **high EPA content, robust growth in saline conditions, and suitability for large-scale cultivation**, making it an attractive ingredient for improving the nutritional profile and sustainability of aquaculture feeds**.** These oils **offer a replacement to fish oil** in diets for species such as Atlantic salmon (*Salmo salar*), gilthead seabream (*Sparus aurata*), and rainbow trout (*Oncorhynchus mykiss*) without compromising growth, health, or product quality (Zatti *et al* 2023; Hossain *et al* 2022; Lee *et al* 2022) though the **level of replacement can vary** and a complete and high quality aquafeeds may need a mix of various ingredients and oils. In many cases, algae oils maintain or even enhance omega-3 n-3 LC-PUFAs fatty acid content in fish muscle, improve immune function, and reduce levels of environmental contaminants such as dioxins and PCBs (Zatti *et al* 2023; Bartek *et al* 2021). However, challenges such as high production costs, technological barriers (e.g., bioreactor optimization), and scalability remain significant hurdles for widespread adoption (Saivenkat *et al,* 2024; Norambuena *et al* 2015). Current inclusion rate of microalgae is estimated at around 1% in aquafeeds with projections that 5% may be realistic in the next five years (European Climate, Infrastructure and Environment Executive Agency, 2025). The topic of algae based alternatives in aquafeeds is covered in detail in a recent report, the report concludes that replacing larger amounts of fish oil and fishmeal in the near future will require policy support in the EU (European Climate, Infrastructure and Environment Executive Agency, 2025). Nevertheless, advances in algae cultivation, especially those utilizing food waste streams, show **promise for reducing environmental impact** and greenhouse gas emissions compared to traditional fish oil (Bartek *et al* 2021; Saivenkat *et al*2024).

Dried microalgae have emerged as a promising plant-based substitute for fishmeal in aquafeeds, offering several nutritional advantages for aquatic species. Microalgae are rich in protein, essential fatty acids, vitamins, and minerals, making them a valuable resource for aquaculture (Vijayaram *et al*., 2024). The protein content of dried microalgae can range from 25% to 70%,

depending on the species and cultivation conditions, which positions them as a viable alternative to traditional fishmeal (Ahmad et al., 2022). Moreover, microalgae often have excellent fatty acid content, particularly the presence of omega-3 and omega-6 fatty acids, which are crucial for the growth and health of aquatic species.

Incorporating dried microalgae into aquafeeds offers advantages, but it also presents challenges. The nutritional value of microalgae can be affected by factors such as species variation, harvesting methods and processing techniques. Additionally, some microalgae species contain antinutritional factors, such as phenolic compounds and polysaccharides, which can hinder nutrient absorption and digestibility. Research is ongoing to identify methods to reduce these negative effects, including fermentation and enzymatic treatments to enhance the digestibility of microalgal biomass (Ahmad *et al*., 2022).

Aquatic species exhibit varying degrees of tolerance to dried microalgae. Many species, including various freshwater fish, have shown positive growth responses when fed diets supplemented with dried algae. However, the effectiveness of algae as a fishmeal substitute can depend on the species, age and dietary requirements of the fish being cultured (Ahmad et al., 2022).

Table 16 – PESTLE analysis for microalgae

Cross-cutting factor	Impact on single cell proteins
Political	The 2021 “Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030” stressed the importance of reducing the reliance of feed producers on fish meal and fish oil taken from wild stocks and encouraging the use of alternative protein materials such as algae or insects or the waste from other industries.
Economic	The large-scale cultivation of algal strains remains challenging due to economic and infrastructure limitations (Napier & Betancor, 2023). Scaling up to commercial production requires significant capital investment to lower production costs and deliver products that meet commercial specifications at a competitive price (Buttle *et al*., 2024).
Social	Algal-derived omega-3 PUFAs are typically non-GMO, simplifying their regulatory approval process and improving consumer acceptance (Napier & Betancor, 2023).
Legal and Regulatory	Commission Regulation No. 68/2013, the Catalogue of Feed Materials. Other plants, algae, fungi and products derived thereof (derived from chapter 3). Feed legislation and the use of GMO biomass in feed and discharged into the environment.
Environmental	Most commercial algal platforms rely on heterotrophic growth, using exogenous, plant-derived carbon sources like sugarcane. This reliance is not always fully accounted for in sustainability claims (Napier & Betancor, 2023). Do not require extensive use of arable land, freshwater, or marine resources and can utilize waste streams as substrates. Furthermore, microbial organisms have significant potential to support circular bioeconomy processes by converting various biomass residues into energy sources for producing single-cell organisms (Buttle *et al*., 2024).

3.3.9. Macroalgae

The proportion of crude protein in macroalgae, particularly when harvested from the wild, is highly variable and varies between species, ranging from 5-45% dry weight (European Climate, Infrastructure and Environment Executive Agency, 2025). Red seaweed generally has a higher protein content than brown or green species but within species protein levels can vary for example the green seaweed *Ulva lactuca* has range of 10-25% protein by dry weight whilst the brown seaweed *Saccharina latissima* and the red seaweed *Palmaria palmata* range from 6-6.3 % and 8-35% respectively (European Climate, Infrastructure and Environment Executive Agency, 2025). Despite having **lower protein content than some other fishmeal alternatives**, macroalgae are a high-quality source of protein, with most species having equivalent, or higher, total essential amino acids as a proportion of total amino acids than traditional agricultural crops and fishmeal. For example, one of the first limiting amino acids in plant-based diets of fish and crustaceans is methionine, which makes up a higher proportion of the total amino acids in macroalgae compared with soybean meal and can be up to twice as high. In contrast, the absolute concentration of essential amino acids on a whole biomass basis is substantially lower in macroalgae (5.5% dry weight) than in soybean meal (22.3% dry weight) and fish meal (31.2% dry weight), due to high concentrations of complex polysaccharides (up to 76% dry weight), also known as dietary fibre. Dietary fibre **limits the digestibility of the algal protein** fractions and affects the overall nutritional value when incorporated into aquafeeds. Accordingly, inclusion levels of macroalgae at rates >10% have been associated with reduced growth performance or feed conversion of commercial fish species, such as seabass (Valente *et al* 2006) and tilapia (Marinho *et al* 2013, Younis et al., 2018). **At levels below ~10%, macroalgae have frequently been reported to provide benefits** such as improved health status, enhanced palatability, feeding stimulation, and potential improvements in product quality (e.g. flavour) of farmed fish. Therefore, the use of macroalgae as a functional feed ingredient or additive in aquafeeds represents a promising approach

3.3.10. Genetically modified (GM) materials

Genetically modified (GM) materials in aquafeeds are components derived from organisms—such as plants, animals, or microorganisms—that have been genetically engineered. This means their genome has been altered using techniques of genetic engineering, resulting in specific traits that are not naturally found in those species. On a legislative basis, a GMO is usually defined as an organism in which an exogenous gene has been introduced, in contrast to gene editing, which involves either the deletion or amplification of an

endogenous gene within the organism (European Commission, 2003a,b; Kumar et al., 2020) ([68]).

These characteristics may encompass improved nutritional value, faster growth rates, resistance to diseases, or benefits related to environmental sustainability. When used in aquaculture feeds, **GM emerging materials aim to improve feed efficiency and conversion ratios, reduce costs and reliance on wild-caught fish, and lower the environmental footprint**—all while supporting the health and growth of farmed aquatic species (Kumar *et al,* 2020).

The use of genetically modified (GM) emerging materials in aquaculture feeds is **subject to stringent safety assessments and regulatory oversight** to ensure protection of animal health, human consumers, and the environment. Safety evaluations typically encompass molecular characterization of the genetic modification, assessment of potential toxicity and allergenicity, nutritional equivalence to conventional materials, and an environmental risk analysis. Molecular characterization focuses on identifying the inserted genetic material, its expression products, and the stability of the modification. Toxicological and allergenicity assessments involve in vitro and in vivo testing, including digestibility studies and animal feeding trials, to detect adverse effects. Nutritional assessments compare the composition and bioavailability of nutrients between GM and non-GM counterparts, ensuring suitability for the target aquatic species.

Environmental risk assessments consider gene flow, persistence of GM material in ecosystems, and potential impacts on non-target organisms and aquatic biodiversity. Regulatory frameworks vary by country but commonly require the submission of a comprehensive scientific dossier to competent authorities, such as the European Food Safety Authority (EFSA), the U.S. Food and Drug Administration (FDA), and Health Canada. These agencies conduct independent expert reviews and may include public consultations. In some cases, post-market monitoring is mandated to detect unforeseen long-term effects. Only GM materials that meet established safety criteria across all relevant domains are approved for commercial use in aquafeeds.

However, while the use of GMO materials in fish feeds has been accepted practice in the Americas (North and South) and Australasia for over 20 years, they are **currently not used in aquaculture feeds in Europe** (Glencross et al., 2020a). The uncertainty of incorporating GMO grains in aquaculture feeds within the EU is primarily influenced by the perceived opposition from consumers and the efforts of environmental nongovernmental organizations (ENGOs) shaping retailer behaviours. Currently, there are no legal barriers to the use of GMO crops in the EU, and they are extensively employed in feed for

([68]) Regulation (EC) No 1829/2003 of the European Parliament and of the Council of 22 September 2003 on genetically modified food and feed

terrestrial animals, such as pigs and poultry, as well as in food intended for direct human consumption. The application of these crops must have been reviewed by EFSA, and there are specific labelling requirements according to EU legislative guidelines ([69]) (European Commission, 2003a,b).

In recent years, several promising genetically modified (GM) species have been developed and evaluated, with particular emphasis on key components such as omega-3 fatty acids, alternative protein sources, and functional feed additives ([70]).

3.3.1. Artemia – hatchery specific feed material

Artemia (brine shrimp) **plays a critical, often irreplaceable, role as the primary live food source** in commercial aquaculture hatcheries, with roughly 3,500–4,000 metric tonnes of dry Artemia cysts marketed annually to support over 10 million metric tonnes of aquaculture production (Madkour et al., 2023). A key advantage lies in the use of Artemia cysts (dormant eggs), which can be stored for long periods, transported globally and hatched on demand within 24–36 hours, offering a highly flexible “off-the-shelf” live feed and reducing the need for complex live-feed culture systems (Sorgeloos et al., 2001). Once hatched artemia can provide a rich source of proteins, lipids, nutrients, and enzymes necessary for rapid growth and early development of many marine species (Sorgeloos, 1980, 2001). Furthermore, as filter feeders, Artemia nauplii can act as effective bio-encapsulation vectors, allowing enrichment with essential nutrients such as highly unsaturated fatty acids (HUFAs), vitamins and probiotics that are directly delivered to larvae, enhancing survival, growth and pigmentation (Lavens and Sorgeloos, 1996). Artemia are particularly useful as a first feed for marine larvae between the depletion of yolk reserves and the stage at which artificial diets become suitable due to the small mouth size of early life stages.

Compared to inert artificial diets, the use of Artemia is consistently associated with lower mortality rates and faster development in hatcheries, particularly for sensitive marine species, while also minimising water quality deterioration when uneaten (Lavens and Sorgeloos, 1996).

In marine finfish hatcheries, particularly for key Mediterranean species such as European seabass, gilthead seabream, meagre, sole and turbot, Artemia plays a critical role during larval rearing. Their use is particularly important for improving survival rates, enhancing larval robustness, and ensuring successful

([69]) Regulation (EC) No 1829/2003 of the European Parliament and of the Council of 22 September 2003 on genetically modified food and feed

([70]) More information is provided in Annex 4

metamorphosis, especially in more sensitive species such as sole and turbot. The ability to enrich Artemia with essential fatty acids and micronutrients further optimises larval performance, making it an indispensable component of hatchery protocols for these high-value finfish species in European aquaculture. Also, for shrimp and prawn hatcheries, Artemia is widely used as the primary feed during the mysis and early post-larval stages, supporting rapid growth and survival.

Production and sustainability trends in the Artemia sector highlight both its global importance and inherent vulnerabilities. **Global production of Artemia cysts remains heavily dependent on a limited number of geographic sources** (Van Stappen et al. 2024). Salt lakes are the primary source of artemia production contributing up to 90% of the global commercial harvest (3,500-4,000 tonnes), with The Great Salt Lake in the United States of America producing around half of global volumes (Van Stappen et al. 2024). In addition to the United States, major production areas include China (approximately 900 tonnes annually) and countries such as Russia and Kazakhstan (around 500–550 tonnes). Other emerging or smaller-scale producers include Uzbekistan (20 tonnes), Vietnam (20 tonnes) and various salt lake and saltern systems worldwide, although their contributions remain comparatively limited (Litvinenko et al. 2015, Van Stappen et al. 2024). The concentration of artemia production on a small number of sources make the industry susceptible to climatic fluctuations and environmental change in these areas. In response to this concern, several countries, including Bangladesh, Vietnam and Thailand, are increasingly developing local Artemia production within integrated salt–Artemia–aquaculture systems, improving supply resilience and supporting rural economies. At the same time, technological innovations are enhancing harvesting efficiency by enabling cleaner separation of nauplii from cyst shells, thereby reducing labour requirements and improving hatchery biosecurity ([71]). Although Artemia continues to dominate as a live feed, ongoing advances in artificial and liquid diets are beginning to offer partial alternatives, particularly in shrimp hatcheries, with the potential to reduce but not fully replace dependence on this critical resource.

Despite this diversification, **global supply remains vulnerable due to its dependence on natural hypersaline ecosystems**, where production is strongly influenced by environmental conditions such as salinity fluctuations and climate variability. This concentration of supply, combined with increasing demand from the expanding aquaculture sector, has raised concerns about long-term sustainability and has prompted efforts to develop alternative sources and improve regional production systems (Lavens and Sorgeloos 2000; Litvinenko et al. 2015; Van Stappen et al. 2020).

([71]) https://artemia.inveaquaculture.com/vi/artemia-revolution/

EU aquaculture is heavily reliant on imported Artemia cysts, reflecting a structural dependency on external supply chains for a critical hatchery input. The vast majority of cysts used in European marine hatcheries, particularly for species such as seabass and seabream, originate from non-EU sources. Domestic production within the EU is not possible due to limited and small-scale or seasonal outputs from Mediterranean salterns, that are insufficient to meet industry demand. This dependence exposes EU aquaculture to supply risks linked to environmental variability (e.g. drought and salinity changes in key producing regions), market fluctuations and geopolitical factors affecting trade. As a result, the availability and price stability of Artemia cysts are critical determinants of hatchery performance and overall production continuity, making them a strategically important (yet externally sourced) input for the European aquaculture sector. Artemia cyst requirement varies depending on time at each life stage, feed conversation ratio, and size at hatch. Among the most common EU species demand for small unenriched artemia ranges from 2-18 kg per million larvae for sole and European seabass respectively and the demand for large enriched artemia ranges from 100-175 for gilthead seabream and sole respectively. Overall, in the EU demand for artemia was estimated 107 tonnes of cysts in 2023. Species specific demands can be found in annex 3.

3.3.2. Material demand for target species in the EU

Typical examples of the material group and the raw material they are derived from are presented in Table 17. The details of the inclusion rates of these groups in diets for different species are provided in the Annex 3.

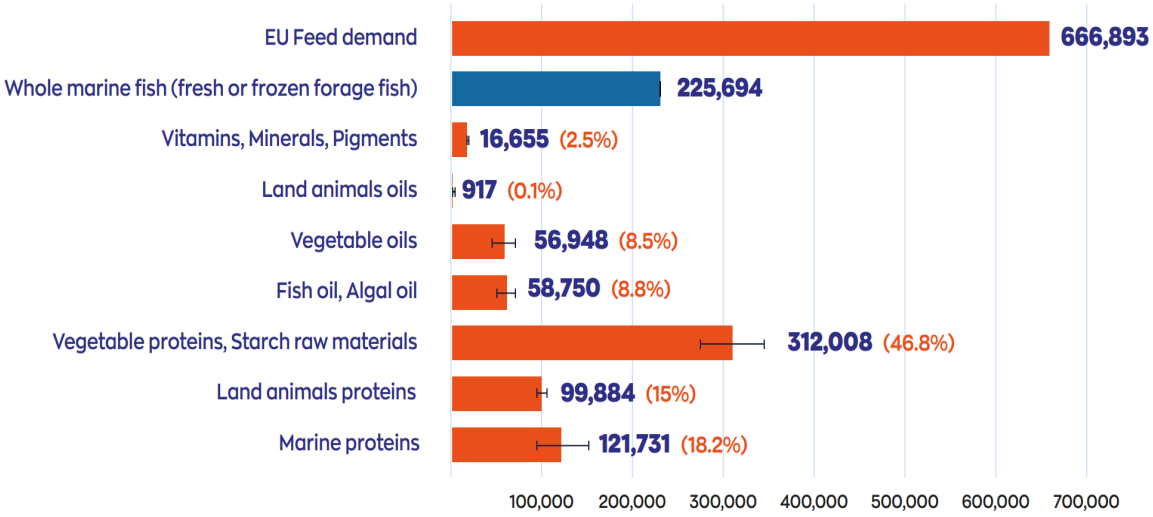
Table 17 – Material groups

Nutrient	Primary raw material	Material group	Typical examples
Protein	Wild-caught and farmed fish and crustaceans	Marine proteins	Fish meal, crustacean meal
	By-products from farmed land (terrestrial) animals	Land animal proteins	Poultry meal
	Agricultural crops	Vegetable proteins	Wheat gluten, Corn gluten Soybean Meal, Soy protein concentrate, Rapeseed meal Sunflower meal, Lupin, Faba
Lipids	Wild-caught fish, farmed fish and crustaceans/algae	Fish oil, Algal oil	Fish oil, Algal oil
	By-products from agricultural crops	Vegetable oils	Rapeseed oil Soybean oil Camelina oil
	By-products from farmed land (terrestrial) animals	Land animal fats	Poultry fat
Carbohydrates	Agricultural crops	Starch raw materials	Wheat

Nutrient	Primary raw material	Material group	Typical examples
Micronutrients		Vitamins, minerals, pigments	Vitamin Premixes Mineral Premixes Pigments

The aquafeed material with the highest demand in the EU is vegetable proteins and starch raw materials (Figure 33) which at 312,000 tonnes make up around 47% of the total material demand in pelleted feeds. In pelleted feeds the materials in the next largest demand are marine proteins (121,700 tonnes), land animal proteins (99,900 tonnes), followed by fish and algal oil (58,800 tonnes), vegetable oils (57,000 tonnes), vitamins, minerals, and pigments (16,700 tonnes) and land animal oils (900 tonnes). In total materials of vegetable and plant origin made up half (55.3%) of material demand for pelleted feeds in EU aquaculture (2023) whilst marine materials made up 27%. Atlantic bluefin tuna are fed whole marine fish rather than pelleted feeds and this demand equated to 225,700 tonnes in 2023.

Figure 33 - Total aquafeed material demand (tonnes) in the EU for the 10 target species (2023)



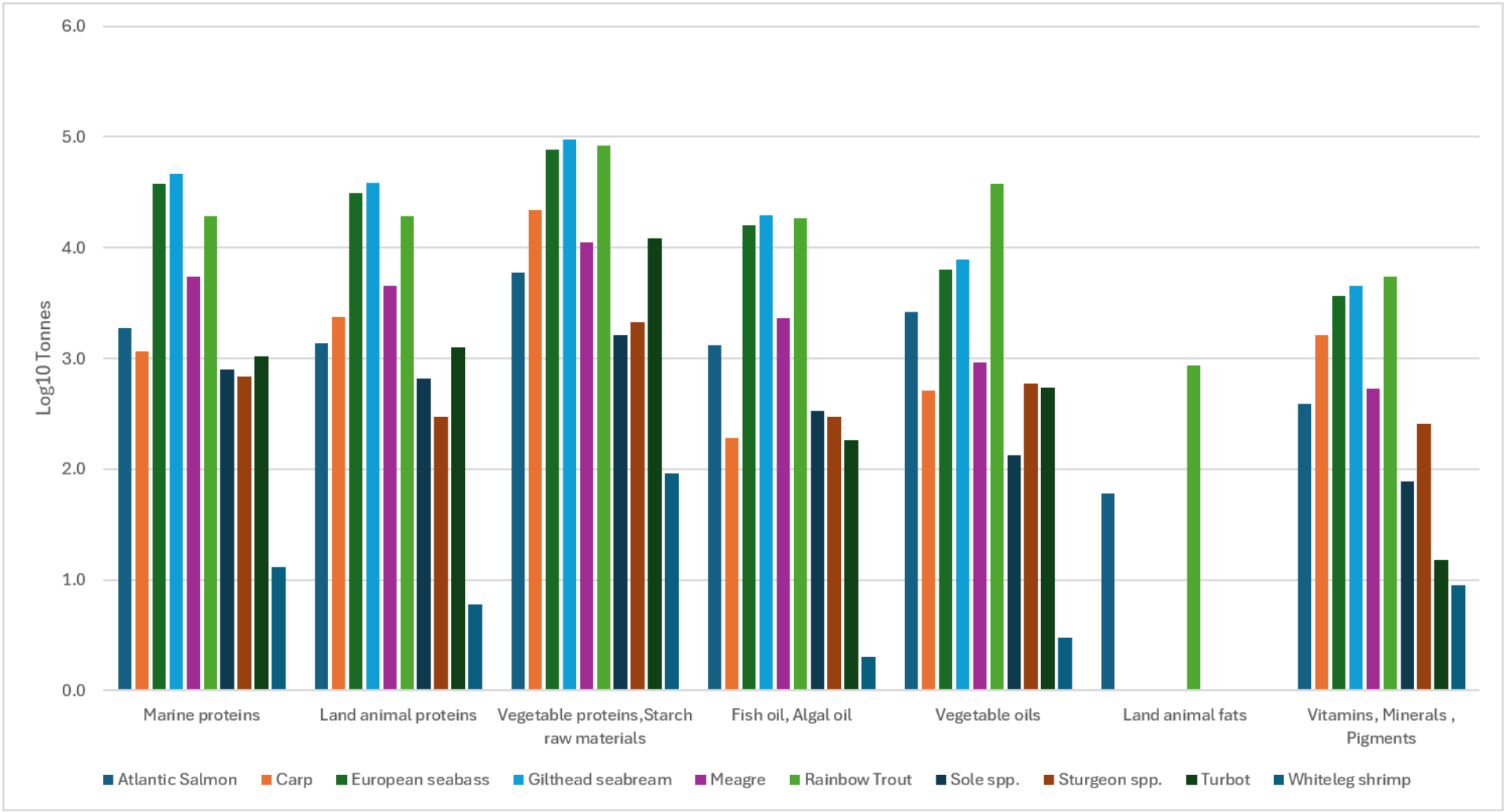
A comparison of material demand between species (2023) is provided below. The Log_{10} of the tonnage has been used to accommodate the wide variation in scales of feed consumption. A summary of key information Is provided for the various materials mentioned in this section 3.3 Aquafeed Materials are provided in Table 18.

Table 18 – Summary of material demand between species (2023) for EU27 in tonnes and Log_{10} tonnes

Materials (tonnes)	Marine proteins	Land animal proteins	Vegetable proteins, Starch raw materials	Fish oil, Algal oil	Vegetable oils	Land animal fats	Vitamins, Minerals, Pigments
Atlantic Salmon	1,878	1,361	5,934	1,301	2,635	60	389
Carp	1,159	2,345	21,929	189	512		1,617
European seabass	37,795	31,512	77,658	16,037	6,387		3,704
Gilthead seabream	46,257	38,567	95,045	19,628	7,817		4,534
Meagre Feed	5,469	4,559	11,236	2,320	924		536
Rainbow Trout	19,314	19,314	84,201	18,458	37,391	856	5,518
Sole spp.	790	659	1,623	335	134		77
Sturgeon spp.	681	298	2,130	298	596		256
Turbot	1,050	1,263	12,161	183	548		15
Whiteleg shrimp	13	6	91	2	3		9
Log10 of volume							
Atlantic Salmon	3.3	3.1	3.8	3.1	3.4	1.8	2.6
Carp	3.1	3.4	4.3	2.3	2.7		3.2
European seabass	4.6	4.5	4.9	4.2	3.8		3.6
Gilthead seabream	4.7	4.6	5.0	4.3	3.9		3.7
Meagre Feed	3.7	3.7	4.1	3.4	3.0		2.7
Rainbow Trout	4.3	4.3	4.9	4.3	4.6	2.9	3.7
Sole spp.	2.9	2.8	3.2	2.5	2.1		1.9

Materials (tonnes)	Marine proteins	Land animal proteins	Vegetable proteins, Starch raw materials	Fish oil, Algal oil	Vegetable oils	Land animal fats	Vitamins, Minerals, Pigments
Sturgeon spp.	2.8	2.5	3.3	2.5	2.8		2.4
Turbot	3.0	3.1	4.1	2.3	2.7		1.2
Whiteleg shrimp	1.1	0.8	2.0	0.3	0.5		1.0

Figure 34 – Summary of material demand between species (2023) for EU27 as Log_{10} (tonnes)



3.4. Aquafeed additives

Additives ([72]) in aquafeed are **nutritive/non-nutritive materials that are supplemented in small amounts** (alone or in combination) for a specific purpose, such as to improve fish growth, the quality of fish as a final product, or to preserve the physical and chemical quality of the diet (Barrows *et al*., 2010), Moreover, growing interest in raising fish in an antibiotic-free environment, driven by consumer interest in the quality and safety of seafood, has hastened the search for safe dietary immunostimulants as an alternative to antibiotics (NRC, 2011).

Feed additives may not be put on the market unless authorisation has been given following a scientific evaluation demonstrating that the additive has no adverse effects, on human and animal health and on the environment. The Feed Additives Regulation (Regulation (EC) No 1831/2003 of September 2003 establishes a common procedure for authorising feed additives and lays down rules for their placing on the market, labelling and use. There are two types of authorisations:

- Authorisations issued to a holder of authorisation. Those authorisations are granted for additives belonging to the categories "Zootechnical additives" and "Coccidiostats and histomonostats" as well as additives consisting of, containing or produced from genetically modified organisms (GMOs).

- Authorisations not issued to a holder of authorisation for substances belonging to the categories of additives "technological additives", "sensory additives" and "nutritional additives".

Both types of authorisations are valid for 10 years throughout the EU and the European Economic Area (EEA). Those authorisations shall be renewable for 10-year period, an application for renewal shall be sent to the Commission at least 1 year before the expiry date of the authorisation. The procedure for renewal is described in Article 14 of Regulation (EC) No 1831/2003, The Regulation also lays down a procedure for modification, suspension and revocation of the authorisation.

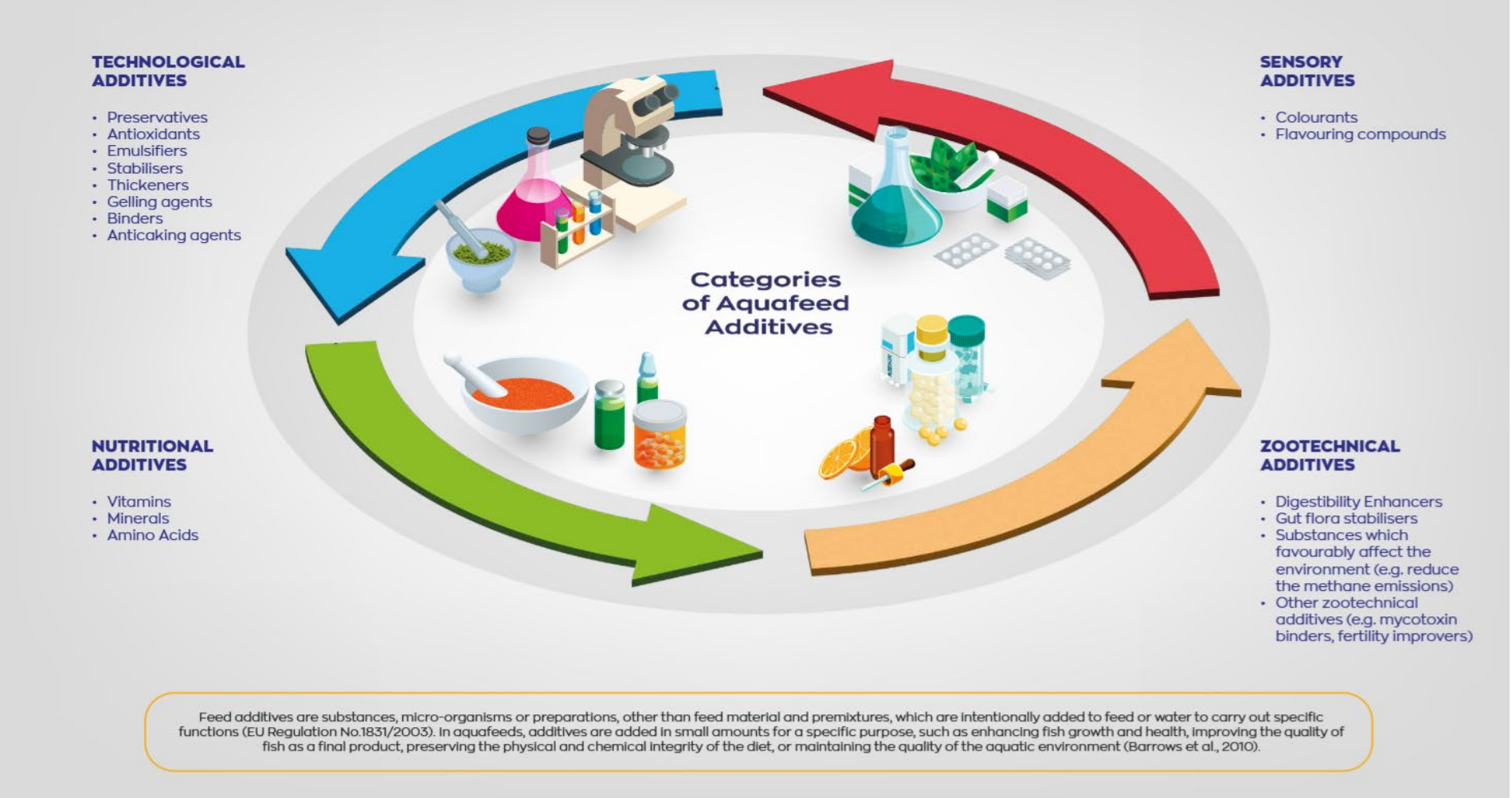
A summary of the additives used in commercial aquafeeds can be found in Table 19 and Figure 35, it is further broken down by species in Annex 4.

([72]) Substances, micro-organisms or preparations, other than feed material and premixtures, which are intentionally added to feed or water in order to perform one or more of the functions to improve the quality of feed and the quality of food of animal origin, or to improve animal performance, animal health and animal welfare.

Table 19 – Additives identified in commercial aquafeeds

Additive Category		Materials
Technological Additives	Preservatives	Sorbic acid, calcium propionate, orthophosphoric acid and sodium Propionate
	Antioxidants	BHA, BHT, propyl gallate and citric acid
	Emulsifiers	Lecithin, phospholipids
	Stabilizers	Guar gum, gelatine, lecithin
	Thickeners	Guar gum, Starch (various)
	Gelling agents	Gelatine
	Binders	Fish gelatine
	Anticaking agents	Calcium carbonate, Tricalcium phosphate
Sensory additives	Colourants	Astaxanthin
	Flavouring compounds	Marine extracts, Yeast extract, Nucleotides
Nutritional additives	Vitamins	A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, choline chloride, inositol
	Minerals	Phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc
	Amino acids	Lysine, methionine and threonine
Zootechnical Additives	Digestibility enhancers	Enzymes, Probiotics, Prebiotics, Organic acids
	Gut flora stabilizers	Probiotics (Pediococcus acidilactici, Leuconostac sp., Lactobacillus sp., Bifidobacterium sp.) Extracts and preparations from Saccharomyces cerevisiae, β-glucans, mannan oligosaccharides.
	Others	Herb extracts

Figure 35 - Overview of Aquafeed additive categories and their functions



3.4.1. Technological additives

A technological additive is any **substance added to feed for a technological purpose,** and which favourably affects the characteristics of feed. The category “technological additives" is further divided into 15 functional groups (Annex I of Regulation (EC) No 1831/2003):

(a) preservatives: substances or, when applicable, micro-organisms which protect feed against deterioration caused by micro-organisms or their metabolites

(b) antioxidants: substances prolonging the storage life of feedingstuffs and feed materials by protecting them against deterioration caused by oxidation

(c) emulsifiers: substances that make it possible to form or maintain a homogeneous mixture of two or more immiscible phases in feedingstuffs

(d) stabilisers: substances which make it possible to maintain the physico-chemical state of feedingstuffs

(e) thickeners: substances which increase the viscosity of feedingstuffs

(f) gelling agents: substances which give a feedingstuff texture through the formation of a gel

(g) binders: substances which increase the tendency of particles of feedingstuffs to adhere

(h) substances for control of radionucleide contamination: substances that suppress absorption of radionucleides or promote their excretion

(i) anticaking agents: substances that reduce the tendency of individual particles of a feedingstuff to adhere

(j) acidity regulators: substances which adjust the pH of feedingstuffs

(k) silage additives: substances, including enzymes or micro-organisms, intended to be incorporated into feed to improve the production of silage

(l) denaturants: substances which, when used for the manufacture of processed feedingstuffs, allow the identification of the origin of specific food or feed materials

(m) substances for reduction of the contamination of feed by mycotoxins: substances that can suppress or reduce the absorption, promote the excretion of mycotoxins or modify their mode of action

(n) hygiene condition enhancers: substances or, when applicable, microorganisms which favourably affect the hygienic characteristics of feed by reducing a specific microbiological contamination

(o) other technological additives: substances or, when applicable, microorganisms added to feed for a technological purpose and which favourably affect the characteristics of the feed

3.4.2. Sensory additives

A sensory additive is any substance, the addition of which to feed **improves or changes the organoleptic properties of the feed**, or the visual characteristics of the food derived from animals (EC, 2003).

The category “sensory” additives is further grouped into two functional groups:

(a) colourants: (i) substances that add or restore colour in feeding stuffs; (ii) substances which, when fed to animals, add colours to food of animal origin; (iii) substances which favourably affect the colour of ornamental fish or birds;

(b) flavouring compounds: substances the inclusion of which in feeding stuffs increases feed smell or palatability,

3.4.3. Nutritional additives

Feed additives are used to **improve the nutritional value of animal feed** and promote the growth and health of animals. These additives include vitamins, pro-vitamins and chemically well-defined substances having similar effect as minerals and amino acids. They are added to animal feed to ensure that the animals receive all the necessary nutrients for their growth and development (Hossain *et al*., 2024),

3.4.4. Zootechnical additives

A zootechnical additive is any additive used to **affect favourably the performance of animals in good health** or used to affect favourably the environment. The category “zootechnical additives” is further divided into four functional groups (Annex I of Regulation (EC) No 1831/2003):

(a) digestibility enhancers: substances which when fed to animals, increase the digestibility of the diet, through action on target feed materials

(b) gut flora stabilisers: microorganisms or other chemically defined substances, which, when fed to animals, have a positive effect on the gut flora

(c) substances which favourably affect the environment

(d) other zootechnical additives

3.4.5. Ten (10) top global and ten (10) top European additives producers

The global market for aquafeed additives is projected to reach approximately USD 1.8 billion by 2024, with continued growth anticipated through 2025, when it is expected to surpass USD 1.9 billion (Future Market Insights, 2025). The Asia Pacific region is forecast to experience the most rapid expansion between 2025 and 2035, accounting for around 45% of global sales. By the end of this period, the global market value is estimated to reach roughly USD 3.2 billion, reflecting a compound annual growth rate (CAGR) of 5.5%.

This **upward trend is largely driven by the expansion of aquaculture operations** worldwide, as the demand for seafood continues to increase. Feed additives play a critical role in aquaculture, contributing to improved health, accelerated growth, and higher productivity among species such as fish, crustaceans, and molluscs. Materials like amino acids, vitamins, prebiotics, and enzymes are being increasingly incorporated into feeds to enhance nutrient uptake, immunity, and overall feed efficiency.

Producers are placing greater emphasis on organic and functional additives that promote digestive health and reduce reliance on antibiotics. Leading companies such as Cargill, ADM, Nutreco, and Alltech are investing in the development of species-specific bioactive and nutraceutical solutions to support sustainable and efficient aquaculture practices. One of the major players is Cargill Incorporated which provides a comprehensive range of feed solutions and additives for various aquatic species. Its global footprint, backed by strong technical support and sustainability initiatives, gives it a leading edge in the market.

Another important company is Nutreco N.V., via Skretting division. Nutreco also emphasises mass nutrition, precision nutrition and innovation in functional feed additives, and has operations in over 40 countries. Evonik Industries, a leading chemical producer, is well prepared in this area through its specialty amino acids and probiotics, which offer performance-enhancing solutions at scale.

Then, there are companies with significant market presence and targeted product offerings but with smaller size and geographical reach. Denmark-based Biomar A/S has a strong presence in functional additives and sustainable aquafeeds. Norwegian Aker Biomarine plays a major role in the supply of krill-based feed additives with a heavy focus on omega-3 for engendering performance and immune support for aquatic animals. Coppens International B.V. was an independent feed company with a focus on innovative high-performance feeds for various species, which was acquired by Alltech and is well established in Europe.

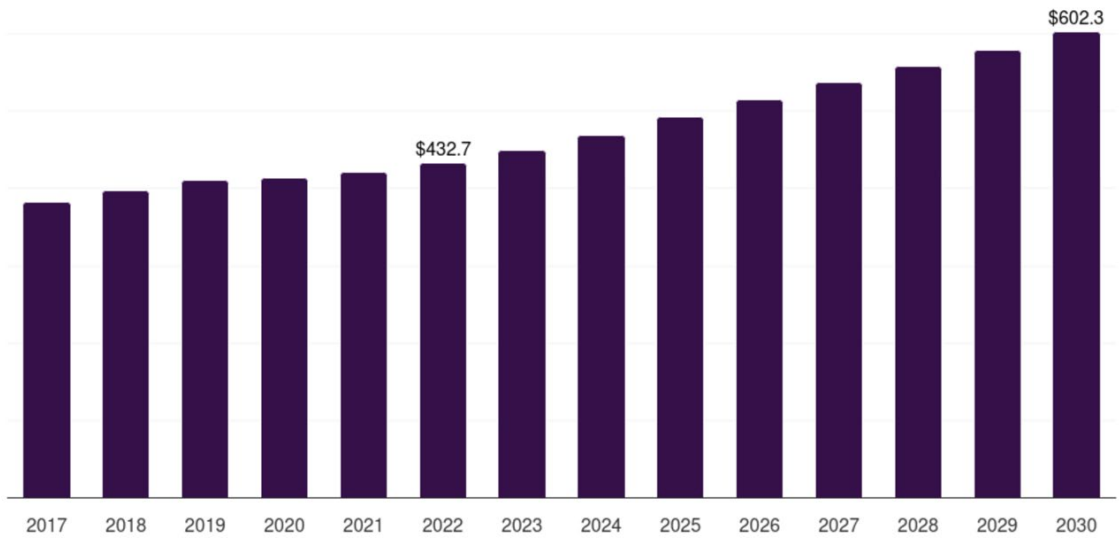
Focusing on Mediterranean aquaculture, Dibaq A.S. provides highly tailored additive formulations tailored for local species and farming systems. These

companies tend to focus on more niche applications, like immune boosters or gut health, and compete by differentiating their products.

Then, there are emerging and regionally active players, gaining traction through innovation, specific product lines, or low-cost offerings. NK Materials Pte. Ltd., a producer in Singapore specialises in natural additives such as squalene and omega-rich supplements. Growel Feeds Pvt Ltd in India, is progressing in the South Asian market with cost-effective aquafeeds and performance solutions including additives. Companies like Beneo GmbH, which focus largely on human nutrition, also play in the animal nutrition space, with plant-based additives such as prebiotic fibres being of interest for gut health in fish.

According to Market Research Intellect, the European additives market within the Food and Agriculture sector is projected to reach USD 8.4 billion by 2031, expanding at a CAGR of 6.5% during 2025–2031 ([73]). Within this broader market, the aquafeed additives segment represents a much smaller share. According to Grand View Research, **the aquafeed additives market in Europe is expected to reach a projected revenue of US$ 602.3 million by 2030**, and a compound annual growth rate of 4.1 from 2025 to 2030.

Figure 36 – European aquafeed additive market revenues in the period 2017-2030 (in million USD)



Source: Grand View Research.

The aquafeed additives market in Europe is witnessing strong expansion, fuelled by the **integration of advanced technologies, rigorous regulatory standards, and a growing emphasis on consumer awareness**. Leading countries such as Germany, the United Kingdom, France and Italy are at the forefront, supported by mature industrial infrastructures and ongoing

([73]) https://www.marketresearchintellect.com

investments in R&D. The region's harmonized regulatory framework promotes innovation and facilitates cross-border collaboration. Additionally, the EU’s sustainability initiatives are encouraging the adoption of environmentally friendly and efficient feed solutions. Collectively, these dynamics underscore Europe's critical and strategic role in shaping the future of the global aquafeed additives industry.

The Europe aquafeed additives market was estimated at USD 468.3 million in 2024 (Grand View Research, 2024) ([74]), whereas the Europe animal feed additives market was estimated at about USD 10.03 billion in 2024 (Straits Research, 2024) ([75]). Aquafeed additives therefore represent approximately 4.7% of the European animal feed additives market (by value) in 2024.

([74]) https://www.grandviewresearch.com/horizon/outlook/aquafeed-additives-market/europe

([75]) https://straitsresearch.com/report/animal-feed-additives-market/europe

3.5. Summary

The European aquafeed sector has experienced moderate but steady growth over the past decade, reflecting both structural constraints and evolving sustainability priorities. Total aquafeed production in Europe (EU and Non-EU) reached approximately 4.8 Mt in 2024, representing 9.1% of global output. Despite its resilience, the EU market remains highly dependent on imports of raw materials such as soy and fish oil, although most compound aquafeed consumed within the EU is produced domestically, indicating a strong degree of self-sufficiency in feed manufacturing.

Feed demand varies significantly across species, driven by production volumes, feed conversion ratios (FCR), and farming practices. Atlantic bluefin tuna exhibits the highest feed intensity, with demand rising from ~180,000 tonnes in 2013 to nearly 500,000 tonnes in 2023, reflecting its reliance on whole fish diets and its high FCR. Rainbow trout remains the most valuable species in the EU in terms of feed expenditure, with annual demand averaging 288,000 tonnes and peaking at 318,516 tonnes in 2021 (EUR 388.9 million). European sea bass and gilthead seabream show moderate growth, with feed demand increasing by 35% and 13.6% respectively over the decade, though their global share has declined due to expansion in non-EU markets. Meagre demonstrates the fastest relative growth, with feed demand increasing ninefold to 25,045 tonnes in 2023, while sole and sturgeon remain niche species with limited but rising feed requirements. Carp feed demand has decreased and is lower than many other finfish in part due to its reliance on cereal crop additions rather than compound feeds. Shrimp farming remains negligible in the EU, with feed demand below 200 tonnes annually.

The EU aquafeed industry is dominated by a small number of multinational producers, including Nutreco (Skretting), Biomar, Aller Aqua, and Coppens, which collectively account for the majority of production. These companies operate globally but maintain strong regional presence through feed mills strategically located near aquaculture hubs. Market competition is shaped by technological innovation, sustainability certifications, and cost efficiency. While exports of EU-produced aquafeed are limited, stricter regulatory requirements and price competitiveness compared to locally produced feeds constrain further expansion into non-EU markets.

The composition of aquafeeds has shifted markedly toward plant-based proteins, which now constitute the majority of formulations for most species. Soybean meal, rapeseed, wheat gluten, and corn gluten are widely used, complemented by marine-derived materials such as fishmeal and fish oil, which remain essential for carnivorous species due to their amino acid and fatty acid profiles. Fishmeal production in the EU averages 420,000 tonnes annually, with a self-sufficiency rate of 76%, though imports from Morocco, Norway, and Chile remain significant. Fish oil production stands at ~140,000 tonnes, with imports

exceeding exports, underscoring continued reliance on external sources. Emerging alternatives including insect meals, microbial proteins, and algae oils offer promising sustainability benefits, but face challenges related to cost, scalability, and regulatory compliance. The aquafeed additive market is growing rapidly, additives offer tools to improve the environmental and economic sustainability of the industry and the EU is well positioned to make the most of market growth with mature industrial infrastructures and an environment that enables and encourages cross-border collaboration.

The EU aquafeed sector future is reliant on balancing growth with environmental and economic sustainability. Key priorities include reducing dependency on marine resources, scaling novel protein sources, and improving circularity through by-product utilization. Regulatory frameworks, while ensuring high standards of safety and traceability, impose complexity and cost burdens that may hinder innovation. EU research funding on the other hand provides support to help address some of the biggest challenges.

4. Supply chain sustainability, traceability & transparency

4.1. Aquafeed environmental aspects – resource requirements & emissions

According to the Product Environmental Footprint Category Rules (PEFCR) for Feed for Food-Producing Animals (Marine Fish PEFCR, 2025), the following stages must be considered to carry out an environmental assessment of feed products: production of feed materials (raw material acquisition and pre-processing), transport of feed materials to the feed mill, feed production (feed processing) and feed delivery to the farm. Besides these factors use on farm the environmental impacts of uneaten or poorly digested feeds should be considered when the environmental sustainability of aquafeed is assessed. Therefore, the following points in the supply chain have been identified as key environmental factors which could compromise the sustainability of the aquafeeds.

4.1.1. Raw material acquisition

Acquisition of raw materials for aquafeed materials is the **main factor affecting the potential environmental impact associated with aquafeed**. The following main type of materials which could be used in aquafeed formulation and the environmental consequences of the use of them are detailed below.

4.1.1.1. Animal-based materials

Fish meal and fish oil can **contribute to aquaculture's carbon footprint**, with some studies showing it accounts for 30.5% to 93% of total emissions derived from aquaculture production (Li *et al,* 2025). Historically fishmeal and fish oil inputs came from reduction fisheries ([76]) and this has raised issues about **stock sustainability and ecosystem impact** (for example, the collapse of Peruvian anchoveta (*Engraulis ringens*) stock in 1970s due, mainly, to overfishing for fish meal production (Guy, n.d.). Today around 39% of fishmeal and 54% of fish oil used in aquafeeds is produced from byproducts (IFFO, 2025) and **aquaculture is thought to be a net producer of fish** with fish-in-fish-out ratios below one even when only fed aquaculture is considered (Boyd & McNevin, 2022).

([76]) Wild caught fisheries not aimed at human consumption. Primarily for fishmeal and fish oil industries.

Regarding the environmental impact linked to the production of PAPs, it is well-known that the production of animals for food is one of the largest sources of carbon-emissions. However, considering that the allocation of environmental burdens is based on an economic allocation, most of the environmental impact associated with animal production should be assigned to the meat for direct human consumption (DHC). This means that the **environmental burdens associated with the by-products are comparatively small** (Campos *et al*, 2019).

4.1.1.2. Plant based materials

Currently **around 75% of all global aquafeed materials are derived from a terrestrial crop** (soy, wheat, canola, corn, rice, etc; (Colombo & Turchini, 2021)., and thus aquaculture is also subject to public debates on the environmental footprint of modern farming methods (Boyd *et al*, 2020; Mungkung *et al,* 2013). Energy use (diesel, fuel, electricity) for greenhouses or machinery use, water consumption for irrigation, land use, emissions from NPK fertilizer production and use and pesticide use (fungicide, herbicide, insecticide) will have significant impact on carbon footprint, eutrophication and human and eco-toxicity (Alhashim *et al,* 2021).

Fry et al. (2016) estimated that production of the top five major **aquaculture feed crops required around 99,000–104,000 km^2 of harvested cropland area** in 2008. As both aquaculture production volumes and the inclusion level of crop versus marine based materials have increased since then, the number today likely stands significantly higher. In this regard, rapeseed required the most harvested area (~ 38,000–40,000 km^2) and resulted in the highest excess nitrogen fertilizer use. Groundnut /peanut production for aquaculture feed requires the most irrigation water, despite being a much smaller absolute feed source by mass, while irrigation water consumption for wheat and rapeseed is sensitive to assumptions about source regions. Soybean and groundnut have comparable excess nitrogen and phosphorus fertilizer use, while the excess phosphorus fertilizer use for rapeseed also illustrates strong sensitivity to sourcing assumptions (Fry et al., 2016). Additionally, plant meal, and specifically soymeal in aquafeeds is linked to global deforestation in countries like Brazil and Argentina. In Brazil, the expansion of soybean plantations is the second largest direct driver of deforestation, covering an area of 562,333 ha in 2020 (Song et al., 2021). Being that **soybeans for aquafeeds make up 6% of the total soy demand**, we could estimate that annually almost 34,000 ha of tropical forest are lost due to aquaculture production ([77]).

Many plant materials contain antinutritional factors (ANFs) which are undesirable components for formulated diets. These compounds can reduce the

([77]) Hannah Ritchie (2021) - “Drivers of Deforestation” Published online at OurWorldinData.org. Retrieved from: 'https://ourworldindata.org/drivers-of-deforestation'

digestibility of meals, particularly in carnivorous fish. Consequently, diets with high levels of primary plant-based materials may reduce nutrient absorption and growth performance, leading to increased nitrogen and phosphorus losses and contributing to **higher pollution loads in the aquatic environment** (Siddik *et al*., 2024).

4.1.1.3. Other materials

The importance of identifying and incorporating sustainable materials into aquafeeds is ever increasing with emerging sources that include insects, seaweed, and a range of single-cell proteins (SCPs) (Carter & Codabaccus, 2022). Regarding insect-based materials, there is evidence that **insects can be a sustainable form of protein for aquafeeds**, especially when fed waste substrates and using renewable energy (Francis et al. 2025). Low land use and water use are particularly positives (Francis et al. 2025, Quang Tran et al. 2022). However, there are significant differences in the reported global warming potential of insect and insect meals. The diversity of species, substrate/feed stock, processing assumptions, energy source make it impossible to allocate one figure for the emissions from insect meal. Another diverging factor is the difference in allocation method with some studies using economic allocation whilst others use mass or no allocation. A recent review found that reported emissions values differed by orders of magnitude between published studies, with values for black solider fly (*Hermetia illucens*) meal ranging from 1.36 to 49.04 Kg CO_2/kg protein (Cantillo and Deshpande, 2025). The International Platform of Insects for Food and Feed (IPIFF) reports that commercial scale production of black solider fly can reach as low as 1.2-1.2 Kg CO2/kg protein meal and 0.82 Kg CO2/kg protein meal for mealworm (*Tenebrio molitor*) (IPIFF, Personal communication)

Regarding the use of microalgae production for aquafeeds, authors highlight numerous benefits, including enhancing fish health, boosting immunity, and improving feed quality. Their use supports sustainable practices by improving water quality, nutrient cycling, and reducing reliance on wild fisheries by replacing dependence to fishmeal or oil (Taelman *et al*, 2013; Vijayaram *et al*., 2024).

Finally, SCP products are derived from the fermentation of microorganisms, such as bacteria, yeast, fungi, or microalgae, and provide a readily available protein-rich (70 %) microbial biomass. **SCP has relatively low environmental footprint** with potential to reduce land use, carbon emissions, and minimized water use, biodiversity loss and deforestation. However, SCP still represents a very low inclusion of protein sources in commercial aquafeeds due to high costs and low availability on the market (Buttle *et al*, 2024).

4.1.2. Raw material pre-processing

Raw material pre-processing is key to optimizing the use of materials by transforming raw material into stable, safe, functional nutritional and digestible materials (meals and oils) for aquafeed. Production processes typically include milling, cooking, drying, fermentation, centrifugation and/or hydrolysing, each with its own energy demand.

Convective drying, spray drying, vacuum drying, microwave drying or heat pump drying are the most common processes for dehydration of agricultural materials. According to Motevali *et al*., (2011), microwave drying alone or combined with other methods shows the lowest energy consumption. It is important to highlight that drying temperatures may affect nutritional and physio-chemical properties of the meals (Ghribi *et al*, 2015), and therefore reduce the absorption of nutrients and increase organic loads to the surrounding environments. **An opportunity to reduce environmental burdens lies in changing the energy source**, while there has been a growing demand for better knowledge of optimised processing methods to improve the nutritional and economic value of the final product and reduce environmental impacts (Hilmarsdóttir *et al*., 2022).

Other pre-processing methods (fermentation or hydrolyzation) could also improve nutrient availability and bioavailability, increase palatability and digestibility and eliminate anti-nutritional compounds in materials, making them more easily digestible, improving growth and health performance, reducing the environmental impact linked to nutrient leaching (Siddik e*t al.*, 2024).

4.1.3. Feed processing

Feed manufacturers develop different specialized production lines which include adaptations of traditional processes as well as grinding, homogenization, extrusion, drying, cooling, coating and crumbling (Samuel-Fitwi *et al*., 2013). Based on the reporting studies of the Marine Fish PEFCR (Product Environmental Footprint Category Rule) technical secretariat, feed production accounts for 230 kWh of electricity, 0.5 l of diesel, and 115 kWh of heat per kilogram of feed produced ([78]). Additionally, according to the Feed PEFCR, on average it accounts for 0.13 m^3 of water per tonne of feed. Industry literature suggests that feed processing contributes a small portion of this total with around 40-60 kWh per tonne of compound feed ([79] [80]). **The consumption of energy may affect directly to climate change environmental impact, while**

([78]) ttps://www.marinefishpefcr.eu/_files/ugd/2c010a_b3c0b101f38f466a85edce2170c298d5.pdf

([79]) https://phileo-lesaffre.com/en/energy-efficiency-in-feed-factories

([80]) https://ebrdgeff.com/projects/implementation-of-a-new-production-line-for-aquaculture-feed/

water consumption may affect to water footprint. Feed processing technologies also influences the palatability of the feed, a crucial factor directly impacting feed intake, growth rates, and the environmental impact, since it will determine also the amount of uneaten feed which may end up in the environment.

Feed packaging can also influence the environmental impact: usually, fish feed is marketed in 25 kg bags of polypropylene (PP). This packaging may act as a source of microplastics, and compromise fish, consumer and environmental health ((Mohsen *et al*., 2024), although this risk remains considerably lower than microplastic contamination of wild fish (Garcia *et al*, 2021; Sultana *et al*, 2023).

Finally, feed producers also determine the feed formulations which is crucial factor affecting nutrient quality, digestibility and therefore feed intake. To improve feed quality, feed producing companies use to include some additives such as probiotics, prebiotics, microalgae, cyanobacteria, enzymes, and immunostimulants (Onomu & Okuthe, 2024).

4.1.4. Transportation

Aquafeed transportation is most commonly conducted through **bulk transportation made by road, train or boat**. As the transportation of other goods, environmental impact of the transportation is highly linked to carbon emissions and resource depletion (consumption of fossil fuels and non-renewable resources). Overall sea transport has the lowest carbon footprint (0.01 kg CO_2-eq/tonne-kilometre), followed by train (0.05 kg CO_2-eq/tonne-kilometre) and finally road transportation (0.2 kg CO_2-eq/tonne-kilometre) (EcoInvent 3.3). However, those are average values which could vary significantly depending on the vehicle/vessel engine type, age and efficiency, used fuel and loads factors (Ritchie, 2020).

4.1.5. Use on farm

Feeding strategies or digestibility of feeds may also affect environmental impact linked to aquafeeds. **Different feeding strategies in aquaculture can play a significant role in the environmental impact** of aquaculture processes and products. Many authors indicate that a large part of this impact is related to the potential environmental effects of marine eutrophication and the carbon footprint caused by uneaten feed. In this regard, the selected feeding strategy can be crucial (Llorens *et al*, 2017).

Over the past decades, various strategies have been developed that can significantly reduce uneaten feed, resulting in both economic and environmental savings. Zhang *et al* (2020) emphasized the role of automatic feeders in

lowering FCRs and feed waste, thereby mitigating environmental impacts associated with excess nutrient discharge and ecosystem degradation (Zhang *et al*, 2020). However, feed size is an important factor to consider in the selection of automatic feeders, as they are designed to accommodate only certain sizes of feed (Thornburg, 2025). Additionally, the integration of automatic feeders with environmental monitoring systems enables adaptive feeding strategies based on real-time water quality data, **improving fish health and reducing feed waste.** Combined with nutrient management practices, these technologies help lower feed conversion ratios and minimize the ecological footprint of aquaculture operations (Chatziantoniou *et al*., 2022; Chellapandi, 2021).

Feeding strategies or digestibility of feeds may also affect environmental impact linked to aquafeeds. Different feeding strategies in aquaculture can play a significant role in the environmental impact of aquaculture processes and products. This is related to the potential environmental effects of **marine eutrophication and the carbon footprint caused by uneaten feed**. This is especially relevant in open-net productions where farmed aquatic animal organic emissions from *excretion* (NH4 and PO4) and defecation, particulate organic carbon (POC) and particulate organic nitrogen (PON), could have a significant impact on eutrophication and biodiversity loss. On the one side, although N and P are not toxins, these biogenic elements are potential harmful in the marine environment if their supply exceeds the assimilation capacity of the ecosystem. On the other side, particulate nutrients affect the sediments and benthic ecosystems below fish farms and in the immediate surrounding area. Severe accumulations can cause major changes in the structure and function of benthic ecosystems locally, i.e., normally resulting in decreasing diversity of the benthic fauna and flora (Olsen e*t al.*, 2008).

4.1.6. Quantitative analysis of resource requirements and environmental impacts of aquafeed materials

Water use ranged from 5-157,813 m^3/t (Mean= 7,961 m^3/t, Median = 1,175 m^3/t), values for calcium phosphate and production astaxanthin respectively. Higher scores were generally found for crops (such as soy), and lower for their extracts (such as wheat gluten and potato starch).

Land requirement values ranged from 0.003 to 15.78 ha/t (Mean = 1.06 ha/t, Median= 0.34 ha/t), for single cell protein and astaxanthin. The latter value may appear inflated due to the concentration of the pigment in the source. Wheat and its products also scored very low in this category.

Electrical energy consumption ranged from 0.03-2,550 kWh/t (Mean = 250 kWh/t, Median = 72.7 kWh/t), in triticale and yeast hydrolysate respectively. Generally, crops had very low scores and the impact of processing was

reflected in the values. For example, soy received a score of 0.046, whereas soy protein concentrate increased to 311.22 kWh/t.

Fossil fuel energy consumption ranged from 1.92 – 2,268,403 kWh/t (Mean= 63,393 kWh/t, Median = 472 kWh/t), for krill meal and astaxanthin respectively. The latter value is an outlier: the upper quartile is 2585 kWh/t.

Greenhouse gas emissions ranged from 0.22-412 t CO_2-eq/t (Mean = 12 t CO_2-eq/t, Median = 2.4 t CO_2-eq/t), again astaxanthin was responsible for widening the range. Imported crops such as soy, had a higher GHG value (5.59) compared to EU crops such as wheat and oats (0.46 and 0.86 respectively).

Eutrophication (marine) ([81]) values had the smallest range in values – from -2.5 (algae oil) to 40.9 kg N eq/t (oats) (Mean = 10.1 kg N eq/t, Median = 7.6 kg N eq/t), whereas ecotoxicity (freshwater) ([82]) had the highest – from 0.33 (calcium phosphate) to 2,110,849 CTUe/t (linseed oil) (Mean = 247,999, Median = 64,896). Most scores of particulate matter ([83]) were very low with an average of 0.00018 disease inc./t if the outlier of calcium phosphate (3.45) is excluded; including this outlier increases the mean to 0.104 disease inc./t (Mean = 0.1080, Median = 0.0001). In any case, the inclusion of calcium phosphate (in shrimp feeds) is very low at 0.5-1.5% so the total impact is mitigated.

A summary of all materials is provided in Annex 5.

4.1.7. Greenhouse gas emissions associated with aquafeed materials

Aquafeed production is a major contributor to the greenhouse gas (GHG) footprint of aquaculture products. These emissions can be broken down into three categories; scope 1, scope 2, and scope 3, which differ based on how directly an organisation (in this case an aquafeed producer) is responsible for them.

- **Scope 1**: Direct emissions from sources the company owns or directly controls (e.g. fuel used on-site in boilers, generators, or company vehicles).
- **Scope 2**: Indirect emissions from the purchase and use of electricity, steam, heating and cooling, whilst these emissions are generated offsite

([81]) Indicator of the enrichment of the marine ecosystem with nutritional elements, due to the emission of nitrogen-containing compounds. Unit used is Kg of nitrogen equivalents.

([82]) Impact on freshwater organisms of toxic substances emitted to the environment, expressed as comparative toxic units for freshwater ecosystems per tonne of material.

([83]) Indicator of the potential incidence of disease due to particulate matter emissions.

they are still attributed to the company as it is a result of the energy it consumes.
- **Scope 3**: All other indirect emissions that occur across the wider value chain, both upstream and downstream. Scope 3 emissions include emissions generated in the production of raw materials, transportation, and the use of products once they leave the producer. These often represent the largest component of farmed seafood GHG emissions.

Across leading aquafeed manufacturers, emissions are consistently reported as CO_2-equivalent (CO_2-eq) using cradle-to-gate life cycle assessment (LCA) methodologies. Under this approach, all Scope 1 and Scope 2 emissions associated with feed manufacturing are included, along with upstream Scope 3 emissions. Downstream Scope 3 emissions, such as those associated with aquaculture farming, distribution, product use and end-of-life, are not typically reported.

This section reviews publicly available sustainability disclosures from major aquafeed companies, including BioMar, Skretting, Cargill, Irida and Alltech Coppens, to look at the GHG emissions per tonne of aquafeed, the relative contributions of Scope 1, 2 and 3 emissions, and the role of key feed materials categories in driving emissions.

Across companies and regions, total emissions intensities that were reported range from ~1.0 to 1.7 kg CO_2-eq per kg of feed (i.e. 1,000–1,700 kg CO_2-eq per tonne of feed) at factory gate. Differences reflect feed formulations, species (e.g. salmonid vs warm-water species), sourcing strategies, and methodologies (e.g. economic vs mass-based allocation).

For example:

- BioMar reports total emissions of ~1.2 kg CO_2-eq per kg of ASC-compliant feed at a Costa Rica feed mill, with similar orders of magnitude reported across other regions.
- Skretting Norway reports a carbon footprint of 1.69 kg CO_2-eq per kg feed in 2023.
- Irida reports a cradle-to-gate footprint of ~0.99 kg CO_2-eq per kg feed in 2023, reflecting feed mix and sourcing choices.
- Alltech Coppens reports an average footprint of ~1.01 kg CO_2-eq per kg of feed, with limited year-on-year variability.

Despite variation, the values are broadly consistent across the sector and reinforce aquafeed as a main point of material emissions within aquaculture value chains.

A consistent finding across all reviewed reports is the **dominance of Scope 3 emissions, which typically accounts for 77–95% of total GHG emissions** per tonne of feed. These emissions primarily arise from upstream production of feed materials, rather than feed mill operations themselves.

Reported breakdowns are presented in Table 20, and include:

- BioMar: ~95% of total emissions attributed to Scope 3 sources, at 1.15 kg CO_2-eq/kg feed ([84]).
- Skretting: Scope 3 emissions of 1.61 kg CO_2-eq per kg feed in 2023, compared with 0.08 kg CO_2-eq per kg from combined Scope 1 and 2 ([85]).
- Irida: Scope 3 emissions account for ~77% of total footprint, with Scope 1 and 2 contributing ~14% and transport ~10% ([86]).
- Alltech Coppens: Scope 3 emissions represent ~92% of total emissions per tonne of feed, and 0.928 kg CO_2-eq/kg feed ([87]).
- Cargill: Total Scope 1-3 emissions equate to 1.96 kg CO_2-eq per kg of coldwater species feed in 2023 (excluding packaging), with Scope 3 raw-material emissions accounting for 1.89 kg CO_2-eq per kg (including land use change) ([88]).

([84]) https://biomar.a.bigcontent.io/v1/static/ASC-FEED-REPORT-Costa-Rica(2024)

([85]) https://www.skretting.com/en-au/sustainability/sustainability-reporting/footprint-report-salmon-feed-2022/Emissions/

([86]) https://irida.com/reports/Sustainability-Report-2023/

([87]) https://www.alltechcoppens.com/uploads/Alltech-Coppens-Sustainability-report-2024-release-2025.pdf?v=1746706435

([88]) https://www.cargill.com/doc/1432261381843/cargill-aqua-nutrition-sustainability-report-2023.pdf

Table 20 – Feed carbon footprint by scope for selected aquafeed producers (as reported or derived)

*Note: Scope values for Irida have been estimated from reported percentages and total shares and are not directly disclosed by the company.

Company	Feed coverage	Scope 1 kg CO_2-eq/ kg feed	Scope 2 kg CO_2-eq/ kg feed	Scope 3 kg CO_2-eq/ kg feed	Total footprint kg CO_2-eq/ kg feed	Method	Source
BioMar	ASC Feed (Costa Rica)	0.059	0.007	1.15	1.22	ASC feed LCA (site-specific)	ASC Costa Rica, 2023
Cargill	Coldwater feed	Not disclosed	Not disclosed	1.89	1.96	Supplier-based Scope 3 LCA incl. LUC	Cargill Aqua Nutrition Sustainability Report
Skretting	Salmon feed	0.02	0.06	1.61	1.69	EU Product Environmental Footprint (PEF)	Skretting Footprint Report 2023
IRIDA	All feed	Scope 1 and 2 combined: ~0.14*		~0.77*	~0.99*	Cradle-to-gate	Irida Sustainability Report 2023
Alltech Coppens	All feed	0.053	0.028	0.928	1.009	ASC-defined feed footprint methodology	Alltech Coppens 2024 Sustainability Report

Furthermore, where companies provide material-level or category-level data, it is possible to note emerging trends. Table 21 and Table 22 below show the GHG emissions per tonne of feed for BioMar ASC Costa Rica and Alltech Coppens, broken down by feed material using economic allocation methodology.

Table 21 – BioMar GHG emissions by feed material in Costa Rica (economic allocation)

Input / activity	Quantity (kg/kg feed)	GHG (kg CO_2-eq/kg feed)
Soy crop	0.38	0.27
Other crop	0.37	0.27
Reduction fishery	0.06	0.06
Fishery by-product	0.09	0.05
Poultry / livestock	0.03	0.02
Other feed	0.01	0.01
Transport and milling	-	0.20
Total	0.94	0.89

Source: https://biomar.a.bigcontent.io/v1/static/ASC-FEED-REPORT-Costa-Rica(2024)

Table 22 – Alltech Coppens GHG emissions by feed material (economic allocation)

Input / activity	Quantity (kg/kg feed)	GHG (kg CO_2-eq/kg feed)
Soy crop	0.01	0.05
Other crop (incl. wheat, maize, and other plant proteins and oils)	0.41	0.30
Reduction fishery	0.03	0.02
Fishery by-product	0.12	0.12
Poultry / livestock	0.25	0.21
Other feed	0.15	0.26
Transport and milling	-	-
Total	0.96	0.96

Source: https://www.alltechcoppens.com/uploads/GHG-Emissions-Report-v1.1.pd

From these data, it is evident that crop materials (such as soy, wheat, maize and other plant proteins and oils) represent the largest contributor to aquafeed emissions due to their high inclusion rates by mass. In BioMar’s ASC feed assessment, crop materials collectively contributed ~0.598 kg CO_2-eq per kg of feed (~49%), driven primarily by soy and other arable crops. While individual crop materials often have lower emissions intensity per kg than animal-derived inputs, their volume means they dominate total emissions. Land-use change (LUC) associated with soy production is also an important driver in some assessments, significantly increasing reported CO_2-eq values depending on methodology.

Regarding poultry and livestock materials, these show high emissions intensity relative to their inclusion rate. In BioMar’s ASC feed analysis, poultry/livestock

inputs contributed nearly 0.3 kg CO_2-eq per kg of feed despite relatively low mass inclusion, making them one of the most emissions-intensive material categories. Similarly, Alltech Coppens reports that land animal materials account for ~21% of total Scope 3 emissions, comparable to marine material contributions.

Within marine materials, distinctions can be seen between reduction fisheries and fishery by-products. In BioMar’s ASC feed, marine feed materials together contributed ~0.12 kg CO_2-eq per tonne of feed, substantially lower than the aforementioned crop and livestock-derived inputs.

Lastly, **plant and marine oils also represent a notable proportion of emissions**, in spite of their low inclusion rates. For example, Alltech Coppens reports plant oils contributing approximately 22% of Scope 3 emissions. Of this, transport and milling account for 10-20% of total emissions.

Amongst the data produced, it is important to note the **geographical and methodological factors that influence emissions**. This can be due to feed material sourcing regions, land-use change assumptions, and the allocation methodology which is either biophysical mass-based or economic allocation. For example, Cargill’s reported feed footprint applies only to coldwater feeds and explicitly includes land-use change, which contributes to a higher reported value. Moreover, reporting both biophysical and economic models improves company transparency, as economic allocation usually yields a lower total emission for marine by-products, and a higher emission for crop materials.

Across these leading aquafeed producers, evidence indicates that **aquafeed GHG emissions are largely material-driven**, rather than being derived from factory processes. Of these emissions, the majority fall within Scope 3, particularly for crops and livestock inputs. It is also worth noting that increasing the use of fishery by-products, and including other alternative proteins, has been highlighted as a way to reduce emission intensity. Overall, the company-level emission intensities are broadly comparable, and average values of the sector emissions can be used where specific material level data are unavailable.

4.2. Stakeholder insights

Regarding the use of fishmeal and fish oil in aquafeeds, **stakeholders viewed (potential) environmental impacts as the more predominant sustainability issues**, with just under 50% considering the use of fishmeal and fish oil having a significant negative impact on exploitation of wild fish stocks and 65% considering the use of fishmeal and fish oil as having a negative or significant negative impact on marine biodiversity and ecosystem balance.

Regarding the production of materials for aquafeed of terrestrial origin (i.e. crops and plant-based materials), survey respondents highlighted potential negative or significantly negative impacts (such as depletion of natural resources and increased energy inputs associated with increasing the usage of non-marine materials.

4.3. Economic aspects – supply chain security & sector employment

4.4. Security of Supply

Following the macroeconomic theory (Mankiw & Taylor, 2020), the quantity supplied of any good or service represents the amount that sellers are willing and able to sell at various price levels. **In the short term, supply is primarily influenced by price changes.** Higher prices result in higher quantities supplied as sellers respond to profit incentives. In the long term, however, beyond price, technological knowledge contributes on increasing productivity, enabling firms to produce more output with fewer resources, thus reducing costs and increasing supply. Natural and social factors, such as weather conditions, natural disasters, and societal preferences (e.g., demand for sustainable products), also affect supply. The cost of production inputs, including land, labour, and capital, is another key factor. Rising input costs reduce profitability, leading to decreased supply, while falling input costs incentivise firms to increase production. The number of sellers in a market also matters, as more sellers increase supply, while fewer sellers reduce it. Together, these short- and long-term factors determine the overall supply of goods and services in an economy. To understand what affects the security of supply for aquafeed materials, i.e., the ability to consistently meet demand, we considered the impacts of these determinants on the quantity supplied in both the short run and long run.

4.4.1. Changes in price and production volume of materials

Regarding price stability, **feed materials demonstrated varying levels of market volatility from 2020 to 2024**, as measured by coefficient of variation (CV=(Standard deviation/Mean)*100) (Table 23). Feed materials with stable pricing (CV <15%) included traditional plant proteins such as corn gluten meal (CV 10%), lupins (CV 10%), and faba beans (CV 11%), marine products like hydrolysates (CV 6%) and krill meal (CV 8%), and feed yeast (CV 4%), which demonstrated exceptional price stability.

Moderate price volatility (CV 15-25%) characterized materials like wheat gluten meal (CV 24%), cottonseed (CV 23%), and poultry by-product meal (CV 24%), suggesting periodic supply disruptions or demand fluctuations. Plant oils exhibited the highest price instability (CV >25%), with palm oil (CV 33%), soybean oil (CV 31%), and rapeseed oil (CV 30%) showing substantial volatility, indicating these supply chains are vulnerable to market shocks.

Similarly, production volume patterns from 2015-2024 also demonstrate varying degrees of supply reliability across feed materials. The most consistent production volumes (CV <10%) were observed in established commodities including soybean products (CV 6%), soybean oil (CV 4%), rapeseed oil (CV 5%), terrestrial animal proteins from chicken (CV 4%) and swine (CV 4%), barley (CV 7%), wheat gluten meal (CV 8%), corn gluten meal (CV 9%), and sunflower meal (CV 9%), indicating stable supply chains capable of meeting consistent demand. Moderate production variability (CV 10-20%) characterized rapeseed meal (CV 11%), sunflower oil (CV 11%), dry peas (CV 14%), and faba beans (CV 19%), suggesting these materials maintain generally reliable supply. High production volatility (CV >20%) was evident in lupins (CV 26%) and cottonseed (CV 24%), with lupins showing extreme fluctuations ranging from 189.7 to 457.4 Mt. In general, there are some key findings as follows:

- Materials rarely show both stable prices and stable production. This creates availability risk, while those with stable production but volatile prices like plant oils.
- Despite having stable production volumes (CV 4-5%), plant oils showed extreme price volatility (CV 30-33%), making them the most market unpredictable materials for feed manufacturers.
- Surprisingly, despite concerns about overfishing and limited resources, marine products like krill meal and hydrolysates showed the fairly price stability (CV 6-8%) among all categories, making them predictable supply chains despite resource constraints.
- Newer protein sources such as single cell materials, particularly feed yeast also with stability (CV 4%), offering reliable pricing.
  Established materials for instance wheat gluten meal and cottonseed experienced significant volatility (CV 23-24%), challenging assumptions about supply chain maturity.
- Fish oil shows significantly higher price volatility than fishmeal. This may be linked to demand from other industries such as human consumption.
- The market price of marine by-products is significantly higher than terrestrial ABPs. These products also show good availability in terms of production volumes.
- The price of single cell proteins is higher than most other materials

Table 23 – Changes in market price and production for aquafeed materials in the EU 2020-2024

Materials	Market price (EUR/tonne)					
	2020	2021	2022	2023	2024	Coefficient of variation
Fishmeal and fish oil						
Fishmeal	1,200	1,100	1,500	1,500	1,300	14%
Fish oil	1,500	2,000	2,900	4,200	1,500	47%
Plant-based protein sources						
Soybean meal	365	410	520	500	430	14%
Soy protein concentrate	850	950	1,200	1,050	980	13%
Fermented soybean meal	700	800	950	880	820	11%
Maize gluten meal	580	640	750	700	660	10%
Rapeseed (Canola) meal	260	310	360	330	295	12%
Vital Wheat gluten	1,100	1,324	1,646	2,055	1,431	24%
Sunflower meal	210	260	330	310	280	17%
Lupins	280	310	370	340	320	10%
Faba beans	250	280	340	310	290	11%
Dry peas	240	270	320	300	280	11%
Barley	180	210	260	240	220	14%
Cottonseed	240	360	430	470	420	23%
Marine products and by-products						
Krill meal	5,454	5,754	6,071	6,405	6,757	8%
Hydrolysates	864	891	927	1,000	977	6%
Plant oils						
Soybean oil	765	1,180	1,670	1,020	950	31%
Rapeseed oil	780	1250	1700	1100	980	30%

Materials	Market price (EUR/tonne)					
	2020	2021	2022	2023	2024	Coefficient of variation
Canola oil	850	1,100	1,500	1,300	1,200	20%
Sunflower oil	1,056	1,719	1,934	1,218	1,270	26%
Palm oil	675	1,000	1,600	900	1,050	33%
Terrestrial processed animal protein sources						
Poultry by-product Meal	395	423	553	615	694	24%
Meat and Bone Meal of swine	220	250	300	280	310	14%
Single-cell materials						
Feed yeast	1,000	1,020	1,050	1,080	1,100	4%
Algae	1,818	1,936	2,062	2,193	2339 / 5000-30 000	8%
Fungal	2,800	2,600	2,400	2,200	2,000	13%
Bacterial	3,800	3,500	3,200	2,900	1600-2700	12%

Source: Market prices and production volume are based on the available findings from chapter 4

Table 24 – Changes in market price and production for aquafeed materials in the EU 2015-2024

Materials	Production volume (million tonnes)										
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	Coefficient of variation
Fishmeal and fish oil											
Fishmeal	4.5	4.0	5.2	4.9	5.0	4.9	4.7	4.6	4.3		8%
Fish oil	1.2	1.2	1.2	1.2	1.2	1.3	1.3	1.0	0.98		10%
Plant-based protein sources											
Soybean products	2.3	2.5	2.6	2.7	2.7	2.6	2.8	2.6	2.8	2.9	6%
Maize gluten meal	58.7	61.9	62.0	64.4	66.7	67.4	71.7	52.4	61.9	59.3	9%
Rapeseed (Canola) meal	22.0	18.8	20.0	18.0	15.3	16.8	17.4	19.6	20.4	16.9	11%
Wheat gluten meal	160.5	131.0	136.7	123.1	138.8	126.7	138.5	134.5	135.4	122.1	8%
Sunflower meal	7.7	8.7	10.1	9.5	9.5	8.9	10.3	9.4	10.1	8.5	9%
Lupins	364.8	293.5	267.0	189.7	224.2	350.0	329.8	457.4	370.2	NA	26%
Faba beans	0.8	0.8	0.9	1.0	1.0	1.3	1.1	1.3	1.3	NA	19%
Dry peas	1.9	2.2	2.7	1.9	2.0	1.9	1.8	1.9	1.9	NA	14%
Barley	62.1	53.2	51.5	49.5	55.2	54.2	52.1	51.8	47.9	50.3	7%
Cottonseed	117.0	103.0	130.0	135.0	158.0	147.0	122.0	97.0	70.0	84.0	24%
Plant oils											
Soybean oil	2.8	2.7	2.8	2.9	3.0	3.0	2.9	2.7	2.8	2.9	4%
Rapeseed oil	10.2	9.4	9.3	9.0	8.9	9.4	9.2	10.2	10.2	9.8	5%
Sunflower oil	3.0	3.3	3.8	3.7	3.6	3.5	4.4	4.0	3.9	3.2	11%
Terrestrial processed animal protein sources											
Chicken meat	10.9	10.0	10.3	10.6	10.8	11.0	10.8	10.9	11.0	11.5	4%
Swine meat	23.2	22.9	22.8	23.2	23.0	23.2	23.6	22.3	20.8	21.3	4%

Source: Market prices and production volume are based on the available findings from Task 4

Figure 37 - Coefficient of variation in the market price of common aquafeed materials 2020-2024 in the EU

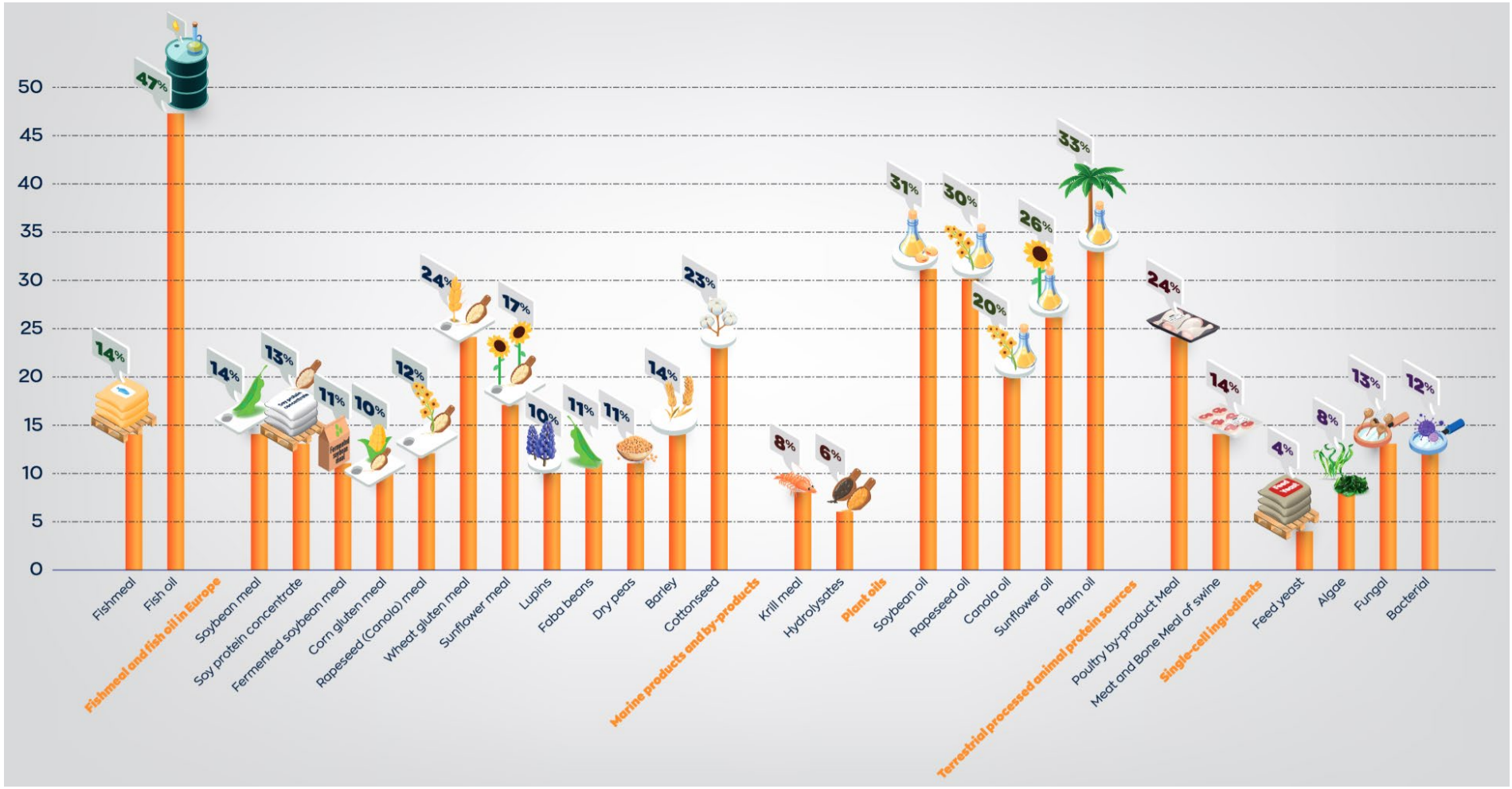
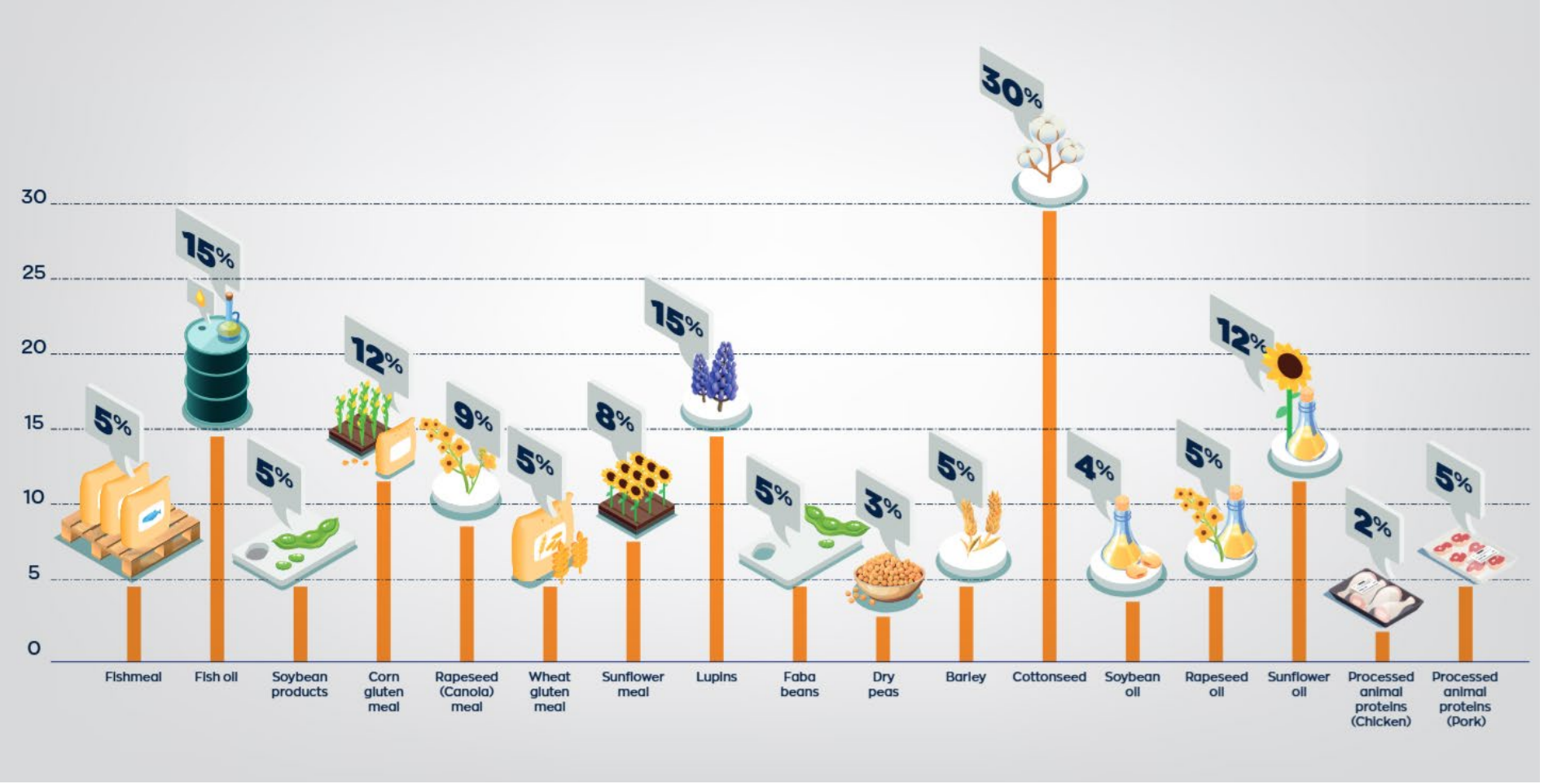


Figure 38 - Coefficient of variation in the production of common aquafeed materials 2020-2024 in the EU



4.4.2. Fluctuations of fishmeal and fish oil prices on the global market

As previously discussed, **fishmeal and fish oil prices have exhibited significant fluctuations over the past decade**, driven by factors such as raw material shortages, fisheries quotas, and increasing global demand for the growth of aquaculture production. Fishmeal prices peaked at USD 1,814.89/tonne in 2023, while fish oil prices reached USD 3,900/tonne the same year due to limited supply, including Peru’s cancelled anchovy fishing season ([89]) and the instance of an El Nino year which have been shown to result in reduced availability of wild-caught fish such as anchovies (Jannathulla et al., 2019). These trends highlight the volatility of traditional aquafeed materials and provide the opportunity to enhance the security of aquafeed supply by adopting alternative materials.

4.4.3. The impact of climate variability

Climate variability is another factor affecting the security of aquafeed materials production, particularly the plant-based materials. As **agriculture is highly vulnerable to climate extremes**, especially droughts and heat stress. For instance, droughts reduce soil moisture and water availability for irrigation, while heat stress during flowering can cause sterilisation and yield losses. There is evidence of past losses in EU agricultural commodities. Maize, wheat, and barley have faced USD 15 billion in drought-related losses between 1983 and 2009, with climate suitability for maize declining in Southern Europe but expanding northward to regions like Denmark (Devot et al., 2023). Similarly, soybeans and oil crops face high yield variability due to heat and drought (Devot et al., 2023). Based on the projection by European Environment Agency (European Environment Agency, 2024) **extreme climate events are expected to become more frequent in the future**.

4.4.4. Innovation in feed formulation

Innovations in aquafeed production are transforming the industry by reducing reliance on traditional materials and greater adoption of alternative, sustainable materials. **Advances in feed formulation have increased the use of by-products.** Between 2022 and 2032, the share of total fishmeal derived from fish by-products is projected to rise from 27% to 30%, while the proportion of total fish oil is expected to remain stable at approximately 53% (FAO, 2024b).

([89]) https://www.seafoodsource.com/news/premium/supply-trade/peru-s-canceled-anchovy-fishing-season-seen-as-necessary-trade-off-for-sustainability

Additionally, oilseed meals have been increasingly used in aquaculture feed formulations. By 2034, their usage in aquaculture is projected to grow by 37%, reaching 11 Mt (OECD/FAO, 2025). The growing array of alternative materials increases the options of aquafeed producers should the availability (either due to price or supply) of traditional feed products decrease (Hodar et al., 2020), this increases the economic sustainability of the industry.

Emerging materials can have restrictions in their inclusion rate tolerable by the fed species and innovations in functional feed additives allow for higher inclusion rates (Hossain et al. 2023). Additives can also improve feed conversion ratios, immune response, and survival therefore improving the economic sustainability of the industry (Okon et al. 2025).

4.4.5. Societal preferences

Ethical concerns about animal welfare and consumption could drive demand for plant-based proteins and alternative protein sources, such as insects and cultured meat (FAO, 2024b). Scientific research showed that consumers generally have a positive attitude toward insect meal as a feed material, as well as toward purchasing and eating farmed fish raised on such diets. This interest is shaped by socioeconomic factors, knowledge, and the importance placed on factors like origin and certification (Mancuso et al., 2016). **Social acceptance of emerging feed materials likely influences their market success.** Additionally, increasing consumer awareness of feed sustainability, coupled with a willingness to pay premiums for responsibly produced food, could support the growth of these innovative feed options (Cottrell et al., 2020).

4.4.6. Stakeholder survey insights

Stakeholders responded to questions regarding the security and supply of different feed materials in the aquafeed supply chains. 41% of respondents viewed the fishmeal supply chain as being reliable and secure, while 45% of respondents viewed the fish oil supply chain as being reliable and secure. Similarly, the supply chains of the plant-based materials soybean meal and maize meal, as well as processed animal proteins (PAPs) and single cell proteins were viewed as considerable and secure. **Stakeholders believed that algae oil and insect oil had the lowest levels of supply chain security** and reliability whilst plant-based materials had the highest.

4.5. Employment

In the EU employment in fishmeal and fish oil production is grouped within the sector of marine living resources which includes primary production (Borriello et al., 2024). The last publicly available report that lists the number of people employed in the EU fishmeal and fish oil sector (catchers and processors) is from 2004 where 2,222 people were said to be employed, 45% in catching, 19% in feed fish processing, and 35% in the processing of trimmings (Oliveira-Goumas, 2003). Since the publication of that report, total EU production of fishmeal and fish oil has decreased with production of fishmeal in 2005 being just over 500,000 and 120,000 tonnes respectively (EUMOFA, 2023a) to around 430,000 and 95,000 tonnes respectively (EUMOFA, 2025). Since the study in 2004 production of fishmeal and fish oil in the EU has decreased by 14% and 20% respectively using the same production to employment ratio this would translate into a drop in employment from 2,000 to 1,911-1,778. However, given the changes in the utilization rate of by-products coupled with two decades of technological improvements the true number is likely to be lower ([90]).

4.5.1. Feed production

Employment specific to the aquafeed, aquafeed material and aquafeed additive sector is not stratified from general aquaculture statistics available in the EuroStat database or STECF economic reports ((European Commission. Joint Research Centre. & Scientific, Technical and Economic Committee for Fisheries., 2025). For compound feeds in general the industry employees over 100,000 people in the EU ([91]) but the vast majority (94%) this production is for poultry (33%), pigs (32%), and cattle (29%). The remaining 6% is spread between animals such as fish, sheep, goats, horse, and rabbits. Assuming a proportional number of employees per animal group, this would equate to 6,000 jobs in the EU producing feed for these species. According to insights from FEFAC, in Europe, employment generated by specific sectors of the feed industry include around 1.5 FTE/1000t of grains produced, and 0.5 FTE /1000t of by-product (FEFAC, 2025).

For five major aquafeed companies from which employment statistics were available, just under 8,500 people were employed globally ([92]), and together those companies produced 5,900,000 tonnes of aquafeed (Table 25). This equates to an average of 802 tonnes of feed per employee. Other available

([90]) A detailed case study related to employment in the soy sector is available in Annex 5

([91]) https://fefac.eu/statistics/

([92]) Employment statistics are not stratified across business areas

data showed that in Egypt, feed mills had on average 1 FTE per 385 tonnes of feed produced (Nasr-Allah et al., 2020).

Table 25 – Number of employees in aquaculture divisions for major feed producers and the amount of feed produced

Company	Number of employees in aquafeed division	Tonnes of aquafeed produced	Tonnes per employee
Cargil	2,015	1,850,000	918
Biomar	1,643	1,372,000	835
Skretting	4,610	2,500,000	542
Irida	104	120,000	1154
Alltech Coppens	125	70,000*	560

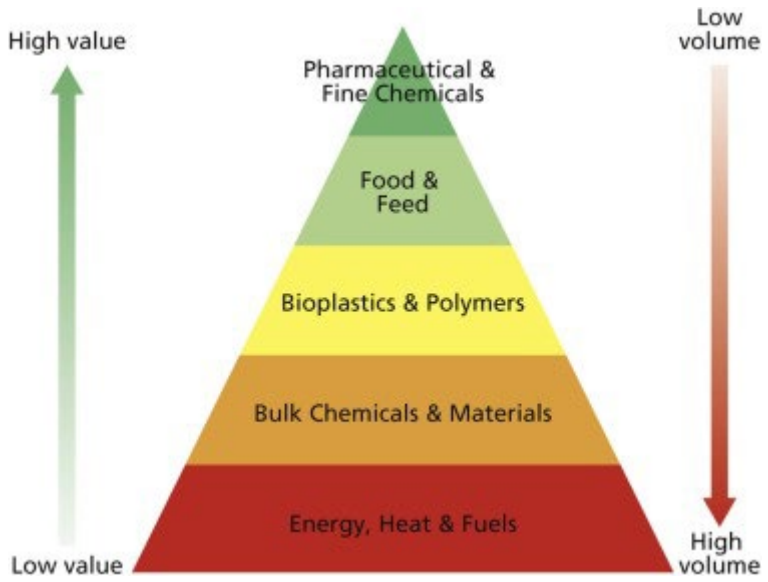
*Approximate figure from industry literature rather than company report

4.6. Economic benefits of waste reduction, circularity, and emerging materials

Circular economy concepts in modern aquaculture include topics like **waste management, nutrient recycling, and the development of emerging feed materials from byproduct streams** (Chary et al., 2024). With the recent launch of the European Union circularity framework, the European feed sector has introduced four key pillars to support the application of circular materials within a European context (FEFAC, 2025). These pillars are: (1) reducing the use of food-grade resources in animal feed, (2) minimizing dependency on land use, (3) prioritizing the use of locally sourced materials, and (4) enhancing the nutritional value of materials.

In a bio-used value pyramid, biomass is first directed to high-value uses like food and feed before lower-value applications. Prioritising the upper tiers of the bio-based value pyramid and waste hierarchy maximises cascading opportunities and resource value (Stegmann et al., 2020).

Figure 39 – Bio-based value pyramid



Source: Stegmann *et al*. (2020).

Few economic analyses have quantified the financial benefits of circularity approach. An example is the production of DHA algae oil (Pillars 2 and 3 in the EU circularity framework), an essential omega-3 source for aquaculture and poultry feeds (Russo et al., 2022). This analysis revealed that switching from standard algal cultivation methods to utilising brewery by-products and dairy wastewater as alternative growth media reduced operating costs by 35% while improving return on investment by 8%. The economic benefits scaled with production capacity, with larger operations realising unit cost reductions of up to 38%. Another techno-economic projection indicated that the cost of EPA and DHA from microalgae biomass could match the price of standard fish oil (30% EPA and DHA) at USD 2,400/tonne (Chauton et al., 2015). However, **achieving economic parity requires addressing key challenges**, including improving biological productivity, optimizing closed photobioreactor systems, and developing cost-efficient harvesting and processing methods (Chauton et al., 2015), this is not something that has been realised at commercial scale currently.

A recent report on the circular proteins for aquafeed in Egypt revealed that high-quality poultry by-product meals (including poultry blood and feather meals, Pillars 1 and 3 in the EU circularity framework) could supply approximately 16% of the total volume and 34% of the protein required for Egypt's annual consumption of 1.5 Mt of tilapia feed. This would significantly lower raw material imports and reduce feed costs (RVO, 2021).

When comparing the price of replacing fishmeal with emerging alternative protein sources at specified replacement ratios (Table 26), the difference varies as shown in the below table. Black soldier fly larvae meal (Pillars 1 and 4) and

single cell protein (Pillars 1 and 2 in the EU circularity framework), both replacing 40% and 30% of fishmeal respectively, result in blended fishmeal costs of EUR 1.57/kg, indicating a slight increase. *Tenebrio molinae* meal, replacing 40%, has the highest blended cost of EUR 2.42/kg due to its material cost ranging from EUR 3.23-4.45/kg. Microalgae *Nannochloropsis* biomass, with a 21.4% replacement, closely matches fishmeal at EUR 1.46/kg. Poultry by-products meal, replacing 30%, offers the most significant cost reduction, lowering the blended fishmeal cost to EUR 1.244/kg.

Table 26 – Comparison of price of blended fishmeal using emerging materials

Material	Replacement percentage	Reference	Price of material (EUR/kg)	Reference	Price of blended fishmeal (EUR/kg)
Fishmeal	-	-	1.47	(EUMOFA, 2023)	-
Black Soldier Fly larvae meal (*Hermetia illucens*)	40%	(Chen et al., 2024)	1.66-1.78	(Nunes et al., 2023; Vodounnou et al., 2025)	1.57
Tenebrio molinal meal	40%	(Modahl & Brekke, 2022)	3.23-4.45	(Niyonsaba et al., 2023)	2.42
Microalgae *Nannochloropsis* Oceania dried biomass	21.40%	(Vázquez-Romero et al., 2024)	1.41	(Vázquez-Romero et al., 2024)	1.46
Poultry by-products meal	30%	(Serra et al., 2024)	0.708	Chapter 4	1.244
Single Cell Protein	30%	(Serra et al., 2024)	1.80	(Jean & Brown, 2024)	1.57

Note: Prices have been adjusted for a 2% inflation rate to reflect values for the year 2025

4.7. Social sustainability

A prevalent opinion is that for something to be considered truly sustainability it needs to incorporate three interconnected aspects environmental, economic, and social (Purvis et al. 2019). The EU is committed to improving social sustainability both within Europe but also to all those impacted by European supply chains. Social sustainability is a core component in the **Corporate**

Sustainability Reporting Directive ([93]) and the **Corporate Sustainability Due Diligence Directive** ([94]) (CSDDD) which require companies identify and, in the case of the CSDDD, address adverse human rights and environmental impacts of their actions inside and outside Europe.

Figure 40 - Sustainability considerations of the EU aquafeed sector including raw material acquisition, (pre-)processing, transportation, and use on farm



4.7.1. Labour practices and wages

Social sustainability is often an overlooked component of sustainability frameworks. Unlike environmental factors, social factors are hard to define and measure as they involve qualitative and context-dependent factors, such as equity, cultural values and fair labour practices. These are often undefined, vague or implicit since they are intangible and lack a consensus of relevant indicators (Alexander et al., 2020). Where social impacts are addressed within

([93]) Directive (EU) 2022/2464 of the European Parliament and of the Council of 14 December 2022 amending Regulation (EU) No 537/2014, Directive 2004/109/EC, Directive 2006/43/EC and Directive 2013/34/EU, as regards corporate sustainability reporting

([94]) Directive (EU) 2024/1760 of the European Parliament and of the Council of 13 June 2024 on corporate sustainability due diligence and amending Directive (EU) 2019/1937 and Regulation (EU) 2023/2859

sustainability, assessments tend to focus on quantitative outcomes such as income, rather than well-being dimensions such as fair treatment and human rights (Dreoni et al., 2022). Labour practices and wages are a core component of social sustainability. **Employment conditions, wage fairness and the distribution of economic benefits** affect the livelihoods of workers and surrounding communities.

4.7.2. FMFO Industry

In recent years, West Africa has become a major emerging global exporter of FMFO, the main fish-based feed material in aquaculture. **Labour practices vary widely depending on geography, fishery governance, and processing infrastructure.** Some regions experience weak regulatory oversight and limited transparency, which has raised concerns about working conditions, wage fairness, and risks of forced or child labour, particularly in informal or small-scale fishery processing. The FAO Fisheries and Aquaculture Circular No. 1236 (Thiao & Bunting, 2022) evaluated labour practices and wages in aquafeed material supply chains in Sub-Saharan Africa. Data pertaining to this labour and wages is limited and not standardised across different actors within fishmeal/fish oil (FMFO) value chains, employment types, and earnings relative to local minimum and living wages. Most facilities do not publicly report employee demographics and wage data are rarely disaggregated, presenting challenges in quantifying employment effects or conducting comparisons across countries and stages of the value chain.

Thiao & Bunting (2022) state that **the expansion of FMFO industries has increased fisher incomes** with increasing market value of the target catch. However, **factory jobs are often temporary**, with factories largely owned by foreign companies and employing migrant or foreign workers, concentrating the locals in lower-grade roles. Some countries such as the Republic of Tanzania and Uganda, report **very low earnings for factory workers** however, wage surveys are generally lacking and there is not currently an assessment of reported pay against the legal minimum wage nor an adequate living wage. Therefore, job and labour creation cannot be treated as inherently beneficial.

Mauritania, Senegal, The Gambia, Republic of the Congo, Ghana, United Republic of Tanzania and Uganda are examples presented by Thiao & Bunting (2022), where stakeholder survey responses were used to evaluate the negative, neutral and positive impacts of the FMFO industry upon labour practices and wages. Mauritania, Senegal, The Gambia, Sierra Leone, Ghana, Congo, the United Republic of Tanzania, and Uganda have all reported increases in factory jobs, as well as indirect roles such as fishers, loaders, and transporters. The United Republic of Tanzania is a clear example, with over 20,000 direct and indirect factory roles. Mauritania has reported 1,972 direct factory jobs, while Senegal documented 129 permanent positions and 264

temporary workers in its factories. Sierra Leone, Ghana, the Republic of Congo, and Uganda also indicated the creation of new jobs, though at lower numbers.

In Mauritania, Senegal, The Gambia, Sierra Leone, Ghana, and the United Republic of Tanzania, this growth in employment has coincided with rising fisher incomes due to greater sales and higher fish prices. However, despite these advances, many workers in Tanzania and Ghana remain poorly paid. Moreover, in nearly all cases, the expansion of job opportunities has been perceived as a **threat to the livelihoods of women and local artisanal fishers**, who face increased competition for fish and raw materials. There is also no clear guarantee that these roles benefit local unemployment levels; many **higher-level positions are reportedly filled by foreign workers**.

Compared to the smaller-scale, emerging FMFO industry in West and Sub-Saharan Africa, there is limited publicly available information on the social sustainability dimensions of FMFO production in South America, despite its much larger-scale facilities. This includes Peru, the world’s largest producer of FMFO, supported by one of the most productive marine ecosystems globally (OECD/ECLAC, 2017). The scarcity of social data reflects broader challenges in transparency and monitoring within industrial reduction fisheries and processing factories. In 2008, Peru recorded 6.1 Mt of landings for indirect human consumption in FMFO manufacture, with anchoveta *(Engraulis ringens)* accounting for 99.8% of this volume (FAO, 2010). Peru’s FMFO sector is characterised by vertically integrated operations and large-scale industrial fleets, generating significant national income but provide limited direct social benefits at the community level.

Despite Peru’s crucial role in FMFO production, social data on labour practices, working conditions, and community well-being remain sparse. Available information comes primarily from voluntary corporate disclosures. For example, one of Peru’s largest FMFO producers, Austral Group (2024), reported implementing a human rights gap analysis across 207 suppliers and offering training on labour conditions, occupational safety, and ethical conduct. The company also outlines employee well-being initiatives, such as psychological support, health insurance awareness, and financial counselling. While such measures indicate an **emerging focus on social responsibility**, they remain limited to specific corporate actors and are **not representative of industry-wide practices**. There is a clear evidence gap on the social sustainability and labour practices of South America’s FMFO sector, particularly regarding wages, occupational health, and the distribution of economic benefits among local communities. Most available sources evaluate Peru’s landscape and concentrate on production efficiency and export performance rather than on-the-ground social outcomes.

Overall, the degree to which the FMFO fits within social sustainability criteria is location specific and there is a need for further research and transparent reporting mechanisms to capture labour and community-level dimensions alongside the economic and environmental aspects of FMFO production.

4.7.3. Soy Industry

Soy, in its various forms (soybean meal (SMB), soy protein concentrate and soy oil), is the most widely used and cost-effective protein source in aquafeeds (Lim et al., 2023), and has been fundamental to the industry’s recent growth. Soy, therefore, provides an interesting case study due to its global use with known sourcing from regions where land use change and agricultural expansion affect local food systems. As of 2019, Brazil has been listed as the world’s leading soy producer ([95]). While soy production generates export revenues, income, employment, and market access for farmers, it has simultaneously been associated with **social conflicts and human rights litigation, as well as environmental disputes** in its producing regions.

Feed manufacturers increasingly rely on third-party certification schemes to mitigate these social risks and demonstrate compliance with best practices. For example, BioMar, a leading aquafeed producer, sources soy through various certified schemes, including the Round Table on Responsible Soy (RTRS), ProTerra, Donau/Europe Soy, and the U.S. Sustainable Soy Assurance Protocol (SSAP) (BioMar Group, 2023). These frameworks integrate labour and social safeguards alongside environmental criteria, covering fair wages, non-discrimination, safe working conditions, and community consultation. The increase of certification schemes among aquafeed producers demonstrates an industry shift toward traceable and socially responsible sourcing.

Demonstrating this broader shift, BioMar’s target to directly engage 100,000 people annually through capacity-building initiatives by 2030 highlights growing recognition that sustainable aquafeed systems depend not only on resource efficiency, but also on empowering communities, farmers, and workers across the value chain. However, certification remains uneven across producing regions, and continued due diligence and engagement are necessary to ensure that commitments can translate into actionable labour improvements seen on the ground.

Cargill is another example of a major aquafeed producer that discloses their environmental, social and governance (ESG) performance through their annual sustainability reporting. Cargill Aqua Nutrition relies heavily on soy, and the company have developed a Policy on Sustainable Soy ([96]), which commits to:

- Promoting the responsible production of soy that benefits farmers and local communities.

([95]) https://www.statista.com/statistics/263926/soybean-production-in-selected-countries-since-1980/#:~:text=From%202015%2F16%20to%202018,metric%20tons%20in%202020%2F21

([96]) https://www.cargill.com/doc/1432136544508/cargill-policy-on-south-american-soy.pdf

- Reducing poverty and improving access to health and education.
- Upholding fair labour practices, ensuring fair wages, and maintaining safe working conditions.

However, in 2019, Cargill was criticised by NGOs for sourcing soy from the Cerrado biome, a Brazilian savannah where approximately 60% of the country’s soy is produced (Yaffe-Bellany, 2019). When sourcing coincides with areas known for unsustainable and exploitative procurement practices, concerns arise around how effectively sourcing is able to align with broader social sustainability commitments, including fair labour and wage standards.

Soy production has been studied for its effects upon local labour and wages, which are often highlighted as one of the main social benefits of the agricultural industry (Dreoni et al., 2022). Quantitative evidence suggests that in producing regions, **the soybean industry increases local wages and household income, drives economic growth, and expands economic and development opportunities** for farmers and rural communities. However, this benefits are sometimes seen alongside an **increase in income inequality** (Choi & Kim, 2016). Furthermore, these improvements do not always translate to better working conditions or greater autonomy, with reports demonstrating limited control over land use and production decisions (Dreoni et al., 2022). While impacts on income have been documented, there is a need for further individual-level research using qualitative methods to capture other, less tangible aspects of labour, such as job security and worker rights.

Overall, it is clear that more can be done to improve the social sustainability of the soy supply chain and given the materials prominence in the aquafeed industry feed producers should continue to build on efforts to source soy that is economically, environmentally, and socially sustainable.

4.7.4. Food and nutritional security

Aquafeed production can influence local food and nutritional security in both positive and negative ways, depending on the material type, production system, and geographic context. The FAO define food security as the availability, access, stability, and biological utilisation of food (FAO, 2001). Aquafeed materials can affect these factors in different ways. For instance, when edible fish is diverted away from human consumption toward fishmeal and fish oil (FMFO), the **availability of nutrient-dense, affordable fish declines in local markets**, particularly affecting lower income consumers (Shea et al., 2025). However, deriving aquafeed from by-products, trimmings, or emerging protein sources can have the converse effect of neutral or even positive gains, by **creating a value in resources that are otherwise discarded** and seen as waste, and in turn supporting local aquaculture production (Thiao & Bunting, 2022).

In addition, food and nutritional security can also be influenced through indirect effects on household access to food. Employment and income that is generated alongside aquafeed value chains can provide workers and farming households monetary access to purchase foods and have varied diets. However, these effects can fluctuate depending on market dynamics; if a demand driven by aquafeed increases pressures on staple or nutrient-rich foods, rendering them scarce or unaffordable, the income gains may not be enough alone to provide access for improved diets. Therefore, the underlying issue is beyond whether aquafeed can create jobs or revenue, but if these opportunities strengthen or weaken a stable and equitable access to nutritious food within their producing regions (Thiao & Bunting, 2022). Whilst aquafeed is the major user of FMFO it is **not certain if reductions requirements by the aquaculture industry would increase availability of fish to local communities**, it is possible that other users of FMFO such as animal feeds and fertiliser would step in to fill the gap left by aquafeeds, likely at lower prices.

Limited research exists on the FMFO production landscape, particularly regarding the location of factories, species of fish consumed, and ownership and trade. Yet this information is key for understanding the implications of FMFO expansions on local and regional food security. As well as diverting fish away from human consumption, factories can be an additional source of environmental pressure, such as pollution, which can affect crop productivity and food systems of surrounding communities (Shea et al., 2025). As mentioned in Section 4.7.1, in recent years, **West Africa has become a major emerging global exporter of FMFO**. In 2021, more than 50 factories were reported across Senegal, The Gambia, and Mauritania (Yonmo & Asanebi, 2022), rely heavily upon small pelagic fish that are abundant in eastern upwellings of the Atlantic ocean and the African Great Lakes Region (Shea, 2024), and are therefore central to local diets (Ruano-Chamorro et al., 2025). Reduction in the availability of these fish has the potential to impact household food and nutritional security(Ruano-Chamorro et al., 2025). While the scale of this impact remains unclear, the expanding presence of FMFO facilities in these regions has propelled case studies and scientific reports to document and assessed localised consequences upon food and nutritional security.

Beyond Africa, limited research is available on the FMFO industry’s implications for food and nutritional security. For instance, South America, although having a central role in **global FMFO production has poor levels of data reporting** and this hinders assessment of the industries impact on social sustainability. Peru alone accounts for the majority of the world’s FMFO output, primarily derived from the anchoveta fishery (FAO, 2010). However, unlike the West African context, anchoveta is largely classified as a non-food-grade species and is rarely consumed domestically, with the majority of landings destined for export-oriented FMFO production (OECD/ECLAC, 2017). Consequently, direct competition with human consumption is limited. The designation of Peruvian

anchoveta is a legal designation ([97]) and not a result of the quality of the wild fish themselves. Peruvian law designates two separate fisheries, one (artisanal / small scale) for direct human consumption and another (industrial) reduction fishery. This designation is in part due to challenges in maintaining food grade levels of this delicate species.

4.7.5. Evidence of Negative Impacts

Across sub-Saharan Africa, th**e fish-based feed (FBF) industry can reduce local food and nutrition security** when fish that is suitable for direct human consumption is sourced from a local fishery and used for FMFO production. The two main impacts of this on the local communities are: 1. Reduced availability of affordable fish in local markets, and 2. Price increases for small pelagic that are staple in low-income diets (Shea et al., 2025).

Four key examples are presented by Thiao & Bunting (2022), illustrating this dynamic. In Uganda, FMFO plants mostly rely on a fish locally known as mukene or dagaa, internationally known as silver cyprinid (*Rastrineobola argentea*). This small pelagic species is an essential food source, heavily relied upon by the country’s poorest consumers. Procurement for aquafeed therefore directly competes with food markets, and the demand surpasses available supply. This in turn puts pressure on its market value, driving price increases beyond the affordability of low-income consumers. The Republic of the Congo is another example, where since 2017, the establishment of a large fish-derived material (FDI) production capacity has placed increasing pressure on a national fish supply that was already in a deficit. Despite access to territorial waters, approximately 40% of fish consumed is imported, and additional industrial demand further exacerbates local shortfalls. In Senegal, a structural gap has been identified between the demand for fish for consumption, driven by population increases and income growth, and domestic supply, which lies at approximately 150,000 t per year (Cai & Leung, 2017). The increased FDI production that relies on otherwise edible fish is therefore a likely contributor toward intensifying local scarcity and upward price pressures. Lastly, in Mauritania, there is a cultural preference for meat and therefore, national diets place less emphasis on fish, in particular small pelagics. However, these species remain an important food source for low-income households that cannot afford meat. Such households are especially vulnerable to the effects of rising prices. The average fish price in Mauritania increased from around 95 USD per t in the early 2010’s, to over 400 USD per t in recent years, significantly reducing both economic and nutrition access for the country’s poorest and more marginalised individuals.

([97]) Decreto Legislativo Nº 1084, Supreme Decree No. 010-2010-produce, and Supreme Decree N.º 005-2017-PRODUCE

With regards to South America, while anchoveta in Peru is largely exported and not typically consumed domestically, Peru still faces nutritional deficits, with fish providing around 23% of animal protein and per-capita consumption at approximately 21.4 kg (FAO, 2010). The diversion of catch to FMFO production reduces the opportunity to increase the local availability of affordable fish, particularly for low-cost processed products that could help mitigate malnutrition. In response, proposals have been made to redirect a portion of anchoveta landings for human consumption, especially as a short-term strategy to improve access to fish in the vulnerable communities (FAO, 2010a).

These examples indicate that the FMFO industry draws on pelagics suitable for consumption, with subsequent effects on local household access to protein and essential nutrients, which **first impacts poorer, more vulnerable groups**, especially in coastal and riparian communities where fish is a primary food source.

4.7.6. Evidence of Neutral or Positive Impacts

Positive or neutral outcomes are most apparent when fish-based feed (FBF) is decoupled from food-grade fish, or when income effects outweigh potential losses in direct fish consumption. One pathway is the use of trimmings, cannery by-products and surplus or non-edible fish. Ghana is one such example, where the FMFO production based on cannery by-products and artisanal processing wastes has the potential to increase net food supply (Thiao & Bunting, 2022). By finding value and thereby **creating a market in resources otherwise considered waste streams** and promoting a more circular economy, fish for human consumption can be left available for local markets (Shea, 2024).

A second pathway arises from the **production of feed in small-scale mills, workshops and farms operations**. In Ghana, Malawi, Senegal, Sierra Leone, Uganda and Tanzania, these facilities produce feed to support farmed fish production that supplies local markets (Thiao & Bunting, 2022). When FBF production is based on processing wastes, byproducts, non-edible species or fish that would be otherwise discarded due to excessive catches or market surpluses, the net effect is an increase in food availability for local consumers. This has the potential to **strengthen local supply of animal-sourced foods** while reducing post-harvest losses.

Income pathways have an important role across all countries assessed in the FAO report (Thiao & Bunting, 2022). The FBF industry provides employment and enterprise opportunities to its workers across the value chain, including harvesting, processing, logistics and ancillary services. The income generated grants the employees greater purchasing power which in turn, enables households access to more diverse foods, thereby improving dietary quality. However, the overall contribution to food-security is susceptible to local

conditions, such as food availability, market prices and cultural preferences. Nonetheless, income gains associated with FBF-related industries are generally recognised as providing tangible benefits to households and communities.

In South America, Peru has the potential to improve domestic food and nutritional security through redirecting the use of anchoveta caught in reduction fisheries destined for FMFO production. The FAO (2010a) note that the development of higher-value anchovy-based products and processing technologies could bridge the population’s protein gap. The Institute of Fisheries Technology (ITP) in Peru has been adapting technologies to manufacture processed products and fitting small-scale vessels with preservation systems for catches destined for human consumption. These interventions could increase local supply without undermining FMFO exports, thereby highlighting a potential pathway for positive nutritional outcomes.

4.7.7. Differences Between Countries and Materials

The impacts of aquafeed on food and nutritional security varies significantly per country and material source. At the country level, the strongest risks are seen where small pelagics are a dietary staple, such as in Senegal and Uganda, where there is already a supply deficit, seen in Congo, or where rapid export of FMFO reduces local availability, for example in Gambia, Mauritania and Senegal. However, where FMFO relies primarily on by-products, such as in Ghana’s use of cannery waste, food security risks can be moderated. Furthermore, compared to West and Sub-Saharan African FMFO industries, where edible small pelagics directly compete with local diets, Peru’s reduction fishery industry presents a contrasting dynamic, whereby the dominant species is largely non-food-grade and export-driven, and there is potential to redirect landings to support domestic nutritional security. This shows how country-specific fisheries management, species composition, and processing infrastructure can shape the correlation between FMFO production and local food availability (FAO, 2010a).

Regarding materials, **fish-based inputs such as FMFO present the greatest risk to local food and nutrition when derived from edible small pelagics**, thereby directly competing with human consumption. The risk is notably lower when production is based on trimmings, waste, or surplus / non-edible catches. Plant-based protein such as soy poses different, typically more indirect risks to local food security. These arise through changes in land-usage, the displacement of food crops, and associated effects upon local prices. Consequently, these risks are shaped more by land governance and market structures, rather than direct competition with local fish consumption.

Other, more emerging sources of protein, including insects and algae, currently show limited direct interactions with local staple foods. However, there is a

potential for indirect effects to emerge, depending on the feedstocks they require for production.

4.7.8. Industry Measures to Improve Food and Nutritional Security

Across the industry, a number of measures targeting both sourcing methods and community outputs can be implemented to improve food and nutritional security of local communities. A key strategy is to **prioritise trimmings, cannery by-products and non-edible/ low-value fish**. By using these sources, FMFO producers can avoid shifting edible, food-grade fish away from local markets, and instead using waste streams to supply feed inputs.

Operational policies can reinforce this, **discouraging procurement of certain species or size classes** important for direct human consumption, especially during seasons or in areas susceptible to acute local scarcity. Another pathway is through safeguarding local markets. This can be achieved through voluntary industry commitments and public **policies that maintain a guaranteed minimum local supply**, such as enforcing landing obligations for human consumption during periods of shortages.

Additionally, measures to **mitigate price fluctuations and improve public access** play another important role. Supporting small-scale fish processors and traders through improving drying, cold chain, and storage stages, can stabilise local supplies and reduce post-harvest loss, thereby limiting cost surges. The development of affordable feeds for domestic aquaculture is also a relevant factor to consider, as this can expand the local availability of farmed fish.

Interventions can also target local income, by ensuring the development of skills, workplace safety, and enterprise opportunities for workers and small businesses involved in FBF value chains. These measures can contribute to improving household purchasing power, reinforcing income-food security pathways.

Further safeguarding can be provided through governance and monitoring frameworks. This includes **integrating social impact assessments that cover explicit food-security indicators** into public policy and third-party audits to improve accountability. This would require data collection and sharing amongst processors, authorities and research bodies, to enable real-time tracking of availability, market prices and dietary impacts at the local level.

Assurances of local food and nutritional security in aquafeed supply chains often originate from the feed material companies themselves, particularly when they source from the producing regions and include such activities as part of broader sustainability commitments. As mentioned in Section 4.7.1, Cargill

publicly disclose company ESG reports providing, an example of industry-led action toward food and nutritional security. To demonstrate these effects of on local food and nutritional security, the policies and associated activities of Cargill are presented to evaluate how such corporate actions can intersect with local food and nutritional security outcomes.

Since 2001, Cargill has partnered with the World Food Program USA in support of the United Nations World Food Programme (WFP), contributing over USD 30 million toward school meal programmes, smallholder farmer livelihoods, and emergency food assistance in Asia, Africa, and Latin America[98]. In the past two years alone, Cargill reports that these initiatives have reached more than 480,000 people across 10 countries. Specific interventions have included:

- Cameroon: cash-based transfers, climate-smart crop production training, financial literacy, and small business management.
- Ethiopia: distribution of more than 1,700 tonnes of wheat to 117,000 people.
- Egypt: food assistance to 9,000 refugees and displaced persons.

These activities aim to address food security challenges related to availability, access, and utilisation, focussing primarily on short- to medium-term needs, rather than tackling the underlying structural barriers which pose the initial risk to local food security in these feed-producing regions.

In parallel, **feed manufacturers have begun to adopt measures to decouple aquafeed production from direct competition with fish suitable for human consumption**, while improving circularity and resource efficiency within their supply chains. For example, BioMar has reduced its inclusion of marine-based materials by more than 70% over recent decades, but continues to rely on FMFO as key nutritional inputs (BioMar Group, 2023). Moreover, BioMar has prioritised the upcycling of marine by-products from both wild-caught and farmed seafood supply chains, as well as from the omega-3 supplements industry. Processing trimmings, viscera, and other non-edible fish parts into high-quality feed materials allows valuable nutrients to be reintroduced into the human food system through aquaculture.

This circular approach is further exemplified through BioMar’s partnerships, such as with Kaura Coproducts, a Spanish firm specialising in the recovery of nutrients from animal by-products. Kaura process feathers and bones into safe feed materials, preventing landfill waste and also supporting a low-impact, deforestation-free supply chain. Their certification to Forética’s SGE 21 standard demonstrates a broader shift toward ethically managed circular inputs in feed production (BioMar Group, 2023).

([98]) https://www.cargill.com/sustainability/doc/1432270798723/2024-impact-report.pdf

4.7.9. Other social sustainability impacts

As previously discussed, the most frequently considered components of social sustainability tend to be those easiest to quantify, which includes labour practices and wages, and food and nutritional security. However, other less-tangible components of social sustainability include **respect for indigenous and local knowledge, individual and collective well-being, equity and the protection of artisanal worker rights, and the provision of safe and healthy working and living conditions.**

Beyond labour and food security, aquafeed companies are increasingly recognising the wider social dimensions of sustainability. For example BioMar’s global graduate programme shows how corporate efforts can build capacity while embedding sustainability values within an organisation (BioMar Group, 2023). The global graduate programme offers a 12-month professional development pathway with training, mentorship, and international collaboration. This programme reflects a growing expectation of employment opportunities within corporations, that are key for their long-term social sustainability. Other efforts seen at BioMar include supplier training, stakeholder engagement, and active participation in public dialogues on sustainable nutrition, which further extend the social impact of aquafeed companies beyond their immediate operations. These actions support the development of an inclusive, informed, and ethical industry that can positively contribute to social wellbeing and environmental stewardship.

Negative impacts of fishmeal and fish oil use on socio-economic aspects were considered less significant (Figure 41). Biosecurity risks (Figure 42) and socio-economic issues (Figure 43) were viewed as less significant potential negative impacts of the increased use of terrestrially produced feed materials.

Figure 41 – Stakeholder responses to the question: Rate the possible negative impacts of the use of fishmeal and fish oil materials in aquafeeds [Socio-economic sustainability issues (e.g. competition with supply chains for human consumption, labour rights issues)] (n=73)

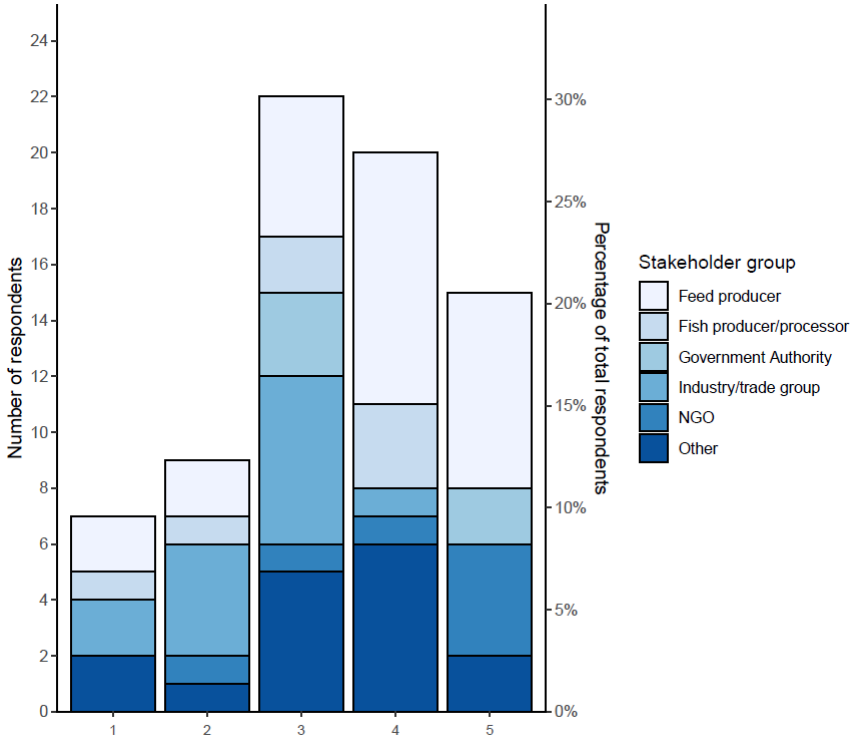


Figure 42 – Stakeholder responses to the question: Rate the possible negative effects of increasing the use of terrestrially produced aquafeed materials [Biosecurity risks (e.g. from increased trade in agricultural crops and products, use of GMOs)] (n=70)

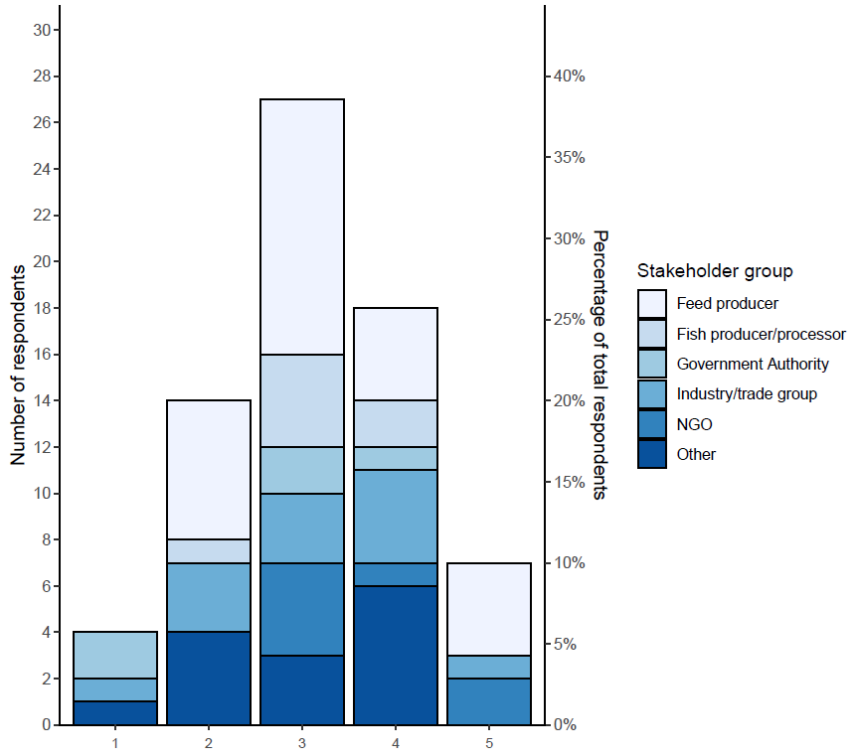
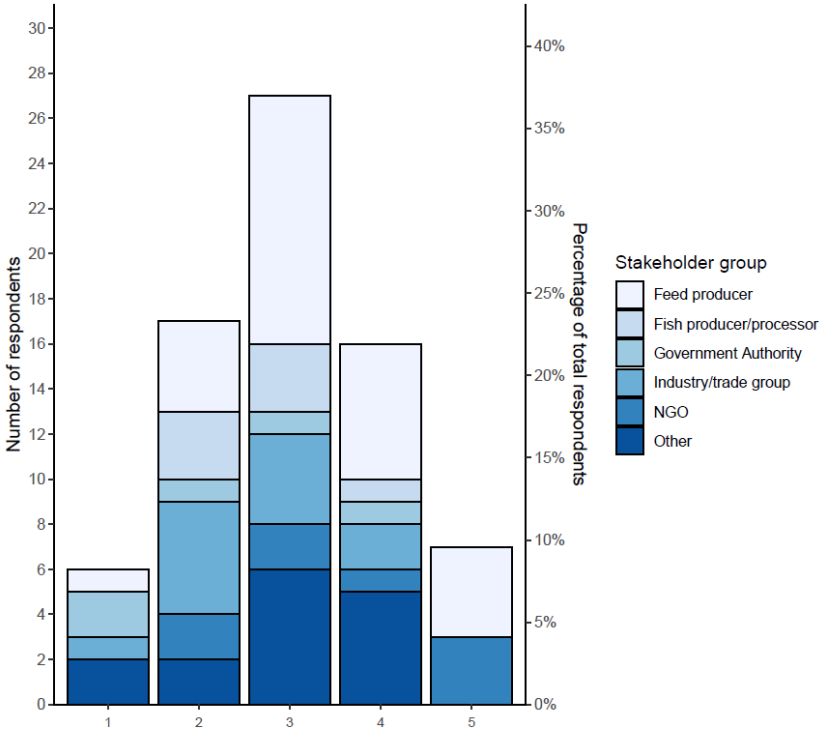


Figure 43 – Stakeholder responses to the question: Rate the possible negative effects of increasing the use of terrestrially produced aquafeed materials [Socio-economic issues (e.g. competition with supply chains for human consumption, labour rights issues)] (n=35)



4.8. Traceability, transparency and sustainability tools

4.8.1. Regulations, voluntary standards and certification in aquafeed traceability

In aquafeed supply chains, traceability and transparency are increasingly recognised as foundational tools to safeguard food and feed safety, environmental integrity, and stakeholder trust. While the EU provides a strong regulatory baseline through regulations such as Reg. (EC) 178/2002 ([99]), Reg.

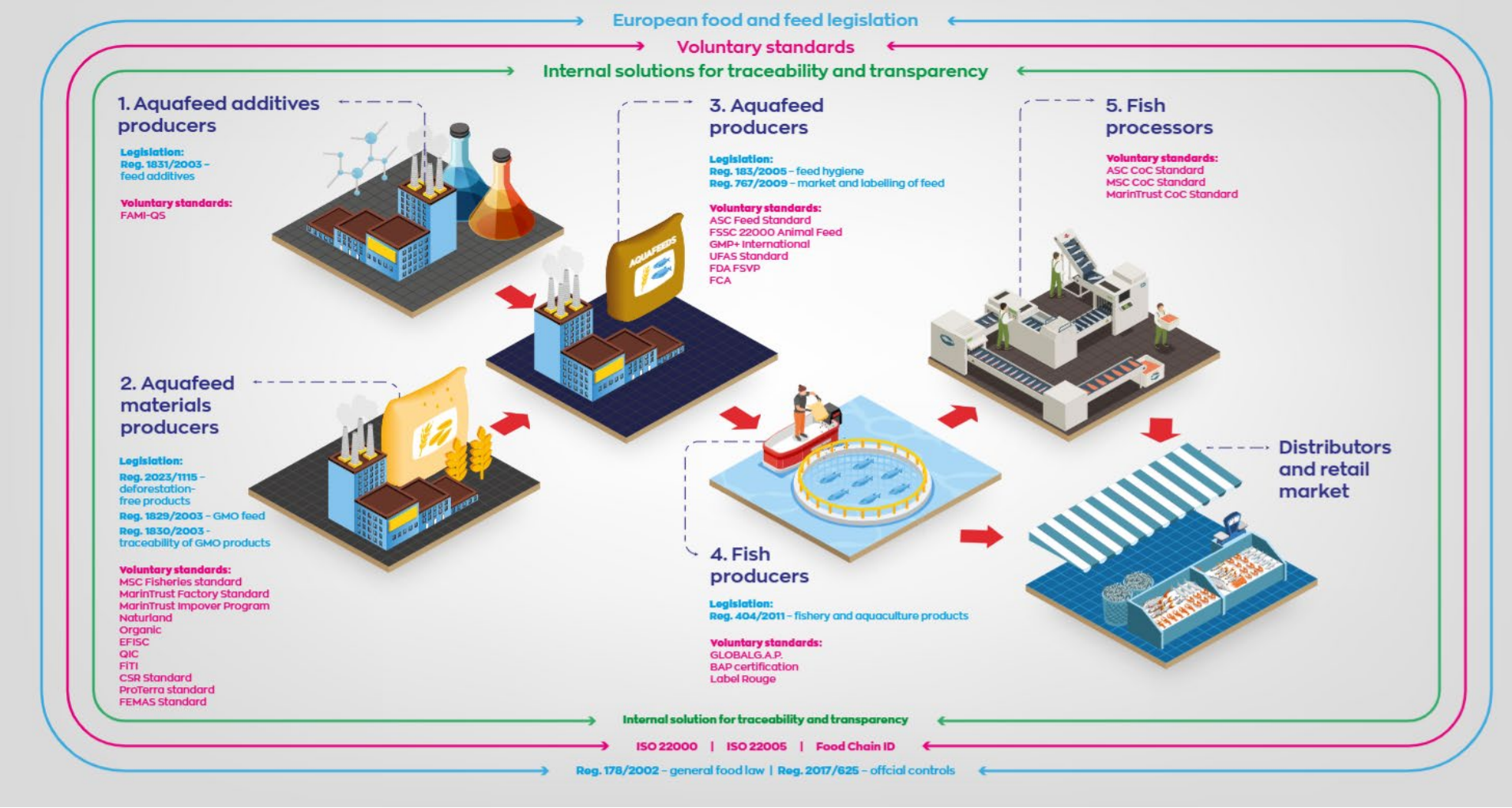
([99]) Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety (OJ L 31, 01/02/2002, p. 1–24 with amendments)

(EC) 183/2005 ([100]), and Reg. (EU) 2023/1115 ([101]), these **regulations are often high-level**, establishing overarching objectives, obligations, and broad principles without over prescription and with flexible implementation modalities. In this context, voluntary standards and certifications play a pivotal role by operationalising traceability requirements and extending them into areas not directly covered by law — especially sustainability, social responsibility, and market communication. An overview of EU legislation and voluntary standards interaction can be found in Figure 42.

([100]) Regulation (EC) No 183/2005 of the European Parliament and of the Council of 12 January 2005 laying down requirements for feed hygiene (OJ L 35, 08/02/2005, p. 1–2 with amendments)

([101]) Regulation (EU) 2023/1115 of the European Parliament and of the Council of 31 May 2023 on the making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010 (OJ L 150, 09/06/2023, p. 206–247 with amendments)

Figure 44 - Interaction of traceability and transparency mechanisms in the aquaculture production chain



4.8.2. Scope and differentiation of voluntary standards

The review undertaken in the report identified several voluntary standards, which vary widely in scope, governance, and intended outcomes, but that are relevant to traceability and transparency across feed, feed material and feed additive supply chains. Despite their diversity, several common elements can be observed:

- Material origin documentation (often to batch level)
- Chain of custody mechanisms
- Supplier verification and risk assessment
- Public auditability or transparency commitments
- Data retention and trace documentation systems

Table 27 – Traceability tools related to aquafeed, aquafeed materials and aquafeed additive supply chains

Traceability tool	Summary
Aquaculture Stewardship Council (ASC) Feed Standard and Chain of Custody Standards	3rd party certification (specific to aquaculture feed production and supply chain)
Best Aquaculture Practice (BAP) Certification	3rd party certification (specific to aquaculture operations)
EFISC-GTP	3rd party certification (specific to feed manufacturing process)
FAMI-QS	Certification related to feed safety and quality
FDA FSVP	Foreign supplier verification rules and tool
Feed Chain Alliance	Voluntary operational standard for feed producers
Fisheries Transparency Initiative Standard	State level good practice framework for fisheries (relevant to reduction fishery producing countries)
FoodChain ID	Digital solutions for operational transparency and logistics
Friends of the Sea	3rd party certification for fisheries and aquaculture production
FSSC 22000	Food safety management system
GLOBALG.A.P.	3rd party certification (specific to aquaculture)
GMP+ International	3rd party certification for feed manufacturing
ISO 22000 and ISO 22005	3rd party certification International standards for operational and management processes
Label Rouge	3rd party certification Standard for farmed fish and seafood
MarinTrust Factory and Chain of Custody Standards, and improver program	3rd party certification schemes specific to reduction fisheries and fishmeal/fish oil production facilities

Traceability tool	Summary
MSC Fisheries and Chain of Custody Standards, and improver program	3rd party certification schemes specific to fisheries
Naturland	3rd party organic certification scheme
ProTerra and CRS (soy traceability)	Voluntary standards (specific to use of soy products)
QIC Quality Import Certification for VQIP	Voluntary standard related to imports (specific to USA)
RTRS (Round table on Responsible Soy)	Certification scheme covering social and environmental sustainability and traceability of soy and maize
SAI (sa8000 standard)	Global social accountability certification
SEMTA	Audit on ethical and social performance available to Sedex members
Universal Feed Assurance Scheme (UFAS)	Voluntary standard related to feed safety and quality

4.8.3. Voluntary standards as a complement to EU legal obligations

Voluntary standards fill significant implementation gaps left open by EU legislation, whereas EU regulation (e.g., Reg. 183/2005 or 767/2009) defines what records must exist, it does not dictate the architecture or technologies to manage them. Whereas standards like FSSC 22000, EFISC-GTP, and ISO 22005 provide templates and audit frameworks that guide operationalisation.

Additionally, certifications like ProTerra or CRS **link aquafeed traceability to deforestation-free supply chains**, addressing environmental risks now regulated under Reg. (EU) 2023/1115. Their systems often include geo-coordinates, plantation-level data, and chain of custody documentation, thus pioneering methodologies that may eventually inform legal standards.

Other standards such as ASC and MarinTrust go above and beyond the requirements laid down by regulations by **requiring material-specific traceability and due diligence** beyond regulatory minimums, including sustainability and social risk assessment. BAP and GLOBALG.A.P. **integrate traceability with environmental, animal welfare, and biosecurity metrics**, these compliment and combine requirements of multiple EU regulations whilst providing defined parameters and reporting guidelines which are not explicitly defined in the regulations.

Voluntary standards often try to address gaps in regulations whilst also providing a more prescriptive set of rules to be followed. An example of this is the ASC Feed Standard, which includes requirements for calculating the mass balance eligible ingrediency volume during feed production. The voluntary standard GMP+ FSA is another example, which states that information on feed

traceability must be available to GMP+ International and competent authorities within 4 hours unless the authorities determine a shorter timeframe.

A summary of the distinct differences in approach and scope can be found in Table 28.

Table 28 – Summary of differences in approach and scope between voluntary standards and EU regulations

Aspect	Voluntary Standards	EU Legislation & Organic Regulation
Legal Status	Non-mandatory; industry or NGO-led	Binding; enforced by competent authorities
Traceability Depth	Often multi-material, batch- or lot-based	Variable, general rules + organic specifics
Auditability	Third-party verification or surveillance	Official controls, but less frequent
Data Disclosure	Some publish audit reports (e.g., ASC)	Rarely public; transparency applies mostly to authorities
ESG Integration	Strong focus (e.g., deforestation, slavery)	Indirect (e.g., through Reg. 2023/1115)
Market Credibility	Enhances brand value, B2B trust	Regulatory compliance baseline

4.8.4. Interoperability and market dynamics

The coexistence of multiple schemes can be challenging for producers, especially SMEs. However, the **alignment of voluntary standards** with ISO or Codex principles improves interoperability and enables mutual recognition (e.g., between FAMI-QS and GMP+). Moreover, these schemes often act as **market gatekeepers**, with large buyers or retailers requiring specific certifications for aquafeed inputs. Importantly, digital traceability platforms (e.g., those aligned with ISO 22005) are being adopted to streamline data capture and enable real-time transparency — addressing both regulatory needs and consumer expectations.

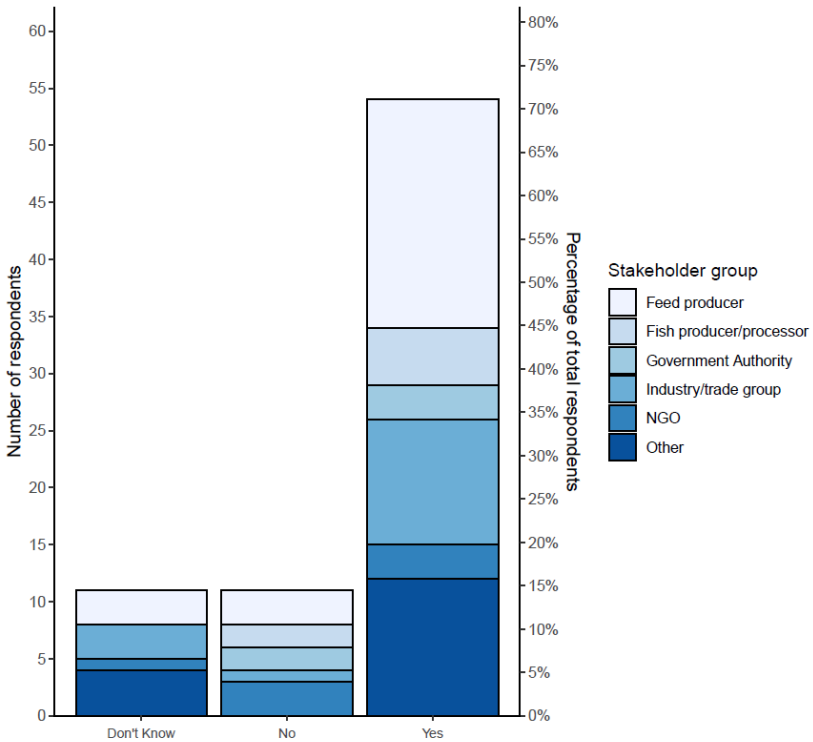
As shown earlier in the task report, EU legislation provides general traceability framework, which is further operationalised through voluntary standards. However, the absence of a uniform model for traceability data exchange results in fragmented and often incompatible internal systems across operators. Large companies typically impose their own digital solutions, forcing smaller suppliers and customers to operate multiple systems in parallel, increasing **administrative burden and costs**. Against this background, guidance on the implementation of interoperable digital traceability systems in aquafeed supply chains would be highly beneficial, particularly for small and medium-sized enterprises.

4.9. Review of certification schemes and their impact on sustainability in the aquafeed sector

A variety of certification schemes and voluntary standards exist that can be applied to aquafeed production and the wider supply chain and the specificities of aquafeed certification schemes have been discussed in detail in other reports under this contract. Whilst each standard is unique as to exactly what elements of the production process are regulated and what elements are left to the discretion of the producer; several key themes emerge.

The list of standards previously identified in this project as relevant to the aquafeed industry were assessed for the inclusion of mandatory sustainability measures. Of the 22 standards assessed **all had some mandatory requirements for traceability and transparency** in record keeping (Annex 1). Traceability in this context typically involves the required ability to trace products back to their source in the event of contamination or other such issues. Around 73% had requirements for specific health and safety, HACCP, or quality management systems. **The majority of stakeholders viewed third party certification as a useful tool** for improving the sustainability of the aquafeed supply chains (Figure 45).

Figure 45 – Stakeholder responses to the question: Do you think third-party certification can enhance sustainability of aquafeed supply chains? (n = 76)



Further details on the role of certification schemes in aquafeed sustainability are included in Annex 5.

4.10. Good practices – corporate social responsibility

4.10.1. Producer good practices

There is growing interest in corporate sustainable responsibility, and companies are increasingly integrating sustainability reporting and goals into their strategy. The increased interest in corporate sustainability is due to a mixture of regulatory compliance such as the EUs directive on corporate sustainability reporting (CSRD) (Directive 2022/2464), normative pressure from initiatives like the UNs sustainable development goals become more widespread (Whittingham et al. 2023), or the financial benefits from increased returns, investment, and consumer demand ([102]). In addition to increased transparency and a more widespread understanding of the financial, social, and environmental impacts of business worldwide, is an increased understanding within companies themselves of the sustainability implications of operations. This increased understanding means that **companies are often better placed than governments or certification schemes to spearhead new sustainability initiatives**. Good practices initiated by companies have the benefit of being adaptable to the specific context to the company rather than generalised in the case of many certification schemes and to be flexible and adaptable in a manner than regulatory measures often aren’t.

The largest aquafeed companies operating in Europe (Skretting, Biomar, Cargil, Irida, De Heus, Aller Aqua, Alltech Coppens, Dibaq, Sparos) were reviewed for common elements and examples of best practices. **Five of the eight companies reviewed released sustainability reports in 2024**, for one company the last report was in 2023 whilst two had no publicly available sustainability report since 2022. The reports differed in their level of detail, focus on aquafeed or the feed production business as a whole, and whether or not they simply reported sustainability metrics or if they specified targets for improvement. At their best the sustainability reports used a double materiality assessment (DMA) considering both the company’s impact on people and the environment but also impacts, risks, and opportunities of each sustainability matter and how it affects the company. Double materiality assessment is a core component of the CSRD although the directives expansion has been postponed following a vote by the European Parliament to delay requirements for all but the largest companies (>1,000 employees) (Directive 2025/794).

Common themes within the sustainability reports with regards to **environmental sustainability include water use, energy use, and waste production**. These metrics are generally focused on emissions and usage

([102]) https://www.ey.com/en_gl/insights/strategy/why-sustainability-has-become-a-corporate-imperative

during the production process rather than the supply chain as a whole. In fed aquaculture (with the exception of cyprinid culture) the production and transport of feed is a significantly smaller producer of GHG emissions than other stages in the aquafeed value chain such as fertilizer production, land use change, energy use in crop production, and crop N2O and CH4 emissions (MacLeod et al. 2020), it is therefore important to calculate and track emissions at other stages of the value chain in addition to the production process. **Examples of good practice include companies that incorporate scope 3 GHG emissions** ([103]) into calculations, this is not standard and even some of the largest producers do not calculate scope 3 emissions. A small number of companies go a step further and have incorporated forest, land, and agriculture (FLAG) emissions targets tracked under the Science-Based Targets Initiative (STBi). The STBi validates targets for companies in line with that the latest science deems necessary to meet the goals of the Paris Agreement ([104]), this helps companies set not only feasible targets for emissions reduction but also targets that will have the most positive impact on the global climate in general. FLAG targets cover greenhouse gas emissions from land use and agriculture, including deforestation, soil management, and feed production. These emissions stem from biological processes described above and require different mitigation strategies than non-FLAG emissions which can generally be tackled through efficiency improvements and the use of renewable energy ([105]). By gaining a deeper understanding of where emissions are generated companies and develop robust strategies to reduce emissions and improve the sustainability of the sector.

Targets for the inclusion of materials from certified sources were a common element across the reports and this is something that mirrors many certification schemes with targets over time set to increase. Another key characteristic was detailing the source of marine materials including percentages of species used and catch areas. Most companies reported forage fish dependency ratio for the feed, with some setting targets for its reduction, something that goes beyond the requirements of certification schemes and EU regulations. It was also common to list the amount of fishmeal and fish oil from trimmings and whole fish with this also being a specific target for improvement for some companies.

Social sustainability focused on **equality metrics such as gender balances and wages and social initiatives in the local community**. In some cases,

([103]) Scope 1 covers direct emissions from owned or controlled sources. Scope 2 covers indirect emissions from the purchase and use of electricity, steam, heating and cooling. By using the energy, an organisation is indirectly responsible for the release of these GHG emissions. Scope 3 includes all other indirect emissions that occur in the upstream and downstream activities of an organisation – The Carbon Trust.

([104]) https://sciencebasedtargets.org/how-it-works

([105]) https://sciencebasedtargets.org/resources/files/SBTiFLAGGuidance.pdf

reports describe the level of due diligence they undertake when sourcing materials, **good practices can include the use of human rights risk rating system** such as that implemented by EcoVadis or other similar human rights due diligence measures.

4.10.2. Buyer led initiatives

The Aquafeed Initiative is a pre-competitive working group coordinated by the Earthworm Foundation ([106]). The initiative joins together ten French retail companies and buyers of seafood products to try and improve the sustainability of farmed fish feed in their supply chain. Initially focusing on salmon, the aims of the initiative include decreasing reliance on reduction fisheries through use of trimmings, emerging materials, and land animal by-products; improving the sustainability of reduction fisheries by limiting the use of fish where there is a direct competition with local human consumption and promoting the use of fish from certified fisheries; and fighting deforestation linked to soybean production.

The Fisheries improvement fund is a multi-stakeholder blue finance solution. Backed by a number of large-scale seafood buyers as well as aquafeed producers Cargill and Skretting the fund aims to catalyse more than US$100 million in investments in fisheries improvement ([107]). The feed companies commit to a volume-based fee that funds fisheries improvement programs and in turn improves the sustainability of supply of fishmeal and fish oil used in aquafeeds.

Driven by market incentives and consumer expectations (Lucas et al. 2021), **supermarkets are increasingly marketing seafood as sustainably sourced**. In the United Kingdom for example nine retail companies make up 97% of the grocery market share ([108]). All nine companies make claims to either currently having or committed to having 100% of own branded farmed seafood products being certified. Two companies with a total market share of 17.4% don’t reveal how much of their current sales of aquaculture products are certified (but are committed to 100%) but the remaining seven with a market share of 79.6% boast greater than 97% of farmed fish being certified with 42.5% of the UK grocery market claiming that 100% of their own farmed fish products are certified. A number of these retailers go further and are actively working with farmers to ensure that feed is from certified or sustainable sources or working with feed companies to improve the amount of emerging feed materials such as

([106]) https://earthworm.org/our-work/projects/aquafeed

([107]) https://finance.earth/fif/

([108]) https://www.grocerygazette.co.uk/2025/02/04/lidl-ocado-thrive-asdas-slump/

insects or algae. The **focus on certified products is strongly market led** but the market share of these retailers has a ripple effect resulting in a strong incentive for producers to become certified and consider sustainable practices more closely.

4.11. Summary

The European aquafeed industry has environmental, social, and economic sustainability implications both within Europe and globally. Environmental sustainability is a key consideration in raw material sourcing, pre-processing, feed manufacture, transport, and use on farm. There are large differences between the materials on their environmental impact including greenhouse gas emissions, eutrophication risk, water use, land use change, and more. Materials such as soy, palm oil, and marine feed materials are in the public spotlight due to their links to deforestation and land-use change (soy and palm) and unsustainable fishing practices (marine feed materials). Other materials such as astaxanthin can have significant environmental impacts per tonne of material but are used in fractional quantities so the relative impact is reduced. The diet used to produce the aquatic species can have a large impact on the sustainability of its production, but this is only half the story and feed conversion ratios are also a key consideration.

Environmental sustainability is the key focus of certification schemes after traceability and safety. These schemes require due diligence of suppliers and some of the more prescriptive schemes have inclusion requirements for certified sustainable feed materials. Certification schemes also require that producers are economically sustainable and offer fair wages to employees, but this does not typically extend to requirements in the supply chain with upstream and downstream areas often outside of the coverage of schemes. While reliable data are not available, estimates suggest that more than one million people are employed in the aquafeed material supply chain worldwide and therefore the industry can have a significant impact on the economic sustainability of workers worldwide. The economic sustainability of the industry is linked to security of supply something that is linked to material price and material availability. Traditional materials such as soy and wheat show a negative correlation between price and supply with price decreasing as supply increases whilst newer emerging materials show positive price-volume correlations with demand increasing faster than supply. The industry, like many others, is vulnerable to climate change and key crop materials are projected to suffer high yield volatility in the future. Fishmeal and fish oil also suffer yield volatility, particularly in El Nino years. This is one of the reasons behind a shift from Peruvian meal to other sources and price fluctuations are driving a search for novel replacements.

Social sustainability is the least included requirement of certification schemes, but awareness is increasing over the impact of the aquafeed industry to the social sustainability of communities worldwide. The fishmeal and fish oil industry is a particular focus and has undergone criticism for unsustainable sourcing practices with poor employment conditions and reductions in local food and nutritional security in some areas of sub-Saharan Africa. Likewise, the soy industry has been criticised for land-use change, disregard for indigenous rights, social conflicts and human rights violations. On the positive side well managed material sourcing can provide livelihoods for some of the world’s most vulnerable and in some areas are net improvement to local food and nutritional sustainability.

A wide range of certification schemes applies to the aquafeed industry. While some critics highlight risks of greenwashing or question the certification of sustainable practices, these schemes are generally viewed as net positives promoting environmental, social, and economic sustainability practices, enhancing transparency and traceability, and improving market access for those certified. Other good practices include producer led requirements over material sourcing and buyer led initiatives to buy fish only from certified producers and requiring produces to use certified feed materials.

As awareness of the impact of the aquafeed industry on sustainability increases worldwide, there is a growing impetus to improve the sustainability of practices and there is strong demand in the EU to be a leader of sustainability in aquaculture production.

5. Conclusions

This study provides a comprehensive assessment of the European aquafeed sector, covering policy and regulatory frameworks, market dynamics, feed material use, sustainability, and traceability. The findings underscore the complexity of aquafeed supply chains and the interplay between environmental, economic, and social factors.

The EU aquafeed sector operates under **one of the most stringent regulatory frameworks globally**. Core instruments such as the General Food Law (Reg. 178/2002), Feed Hygiene Regulation (Reg. 183/2005), and Feed Marketing and Use Regulation (Reg. 767/2009) ensure high standards of feed safety, traceability, and quality. However, stakeholder feedback reveals persistent challenges in navigating overlapping rules and compliance costs, particularly in relation to the Deforestation-Free Products Regulation (Reg. 2023/1115) and animal by-product legislation.

International standards (Codex Alimentarius, WOAH Aquatic Animal Health Code, FAO Guidelines) complement EU law, aided by a wide range of voluntary certification schemes both aquaculture specific and more generally applicable. **Norway and the UK largely mirror EU requirements**, minimizing trade disruptions, although Brexit has introduced third-country compliance obligations for UK exports.

The European (EU and Non-EU) aquafeed market has shown resilience, with production reaching 4.8 Mt in 2024, representing 9.1% of global output. Growth is driven by feeds for high-value species such as Atlantic salmon, seabass, and seabream. **Feed demand varies widely by species**, reflecting differences in feed conversion ratios (FCR), life-cycle requirements, and differences between intensive and extensive farming systems.

Material composition has shifted significantly over recent decades. **Plant-based proteins now account for ~75% of fed diets**, reducing reliance on marine resources. Nevertheless, **fishmeal and fish oil remain critical for carnivorous species** due to their unique amino acid and fatty acid profiles. Emerging materials such as insect meals, microbial proteins, and algae oils offer promising alternatives but face scalability, cost, and regulatory hurdles. Price volatility in key inputs also affects formulation strategies and supply chain stability.

Environmental sustainability is a defining concern for the aquafeed sector. Life Cycle Assessment (LCA) data reveal substantial variability in resource use and greenhouse gas emissions across feed materials. Marine-derived materials, though nutritionally superior, and typically having lower GHG

emissions per unit than plant based materials, raise concerns over biodiversity and ecosystem impacts, despite increasing use of trimmings and by-products.

Plant-based materials, while reducing pressure on marine stocks, introduce challenges related to land use, deforestation, and freshwater consumption. The Deforestation-Free Products Regulation directly addresses these concerns but adds compliance complexity**. Novel materials such as insects and SCPs show potential for circularity** and reduced land footprint, though energy intensity, cost, and scale remain barriers.

Traceability systems mandated under Regulation 183/2005 provide robust oversight, complemented by voluntary certification schemes (e.g., ASC Feed Standard, MarinTrust, GLOBAL G.A.P.). **These tools enhance transparency and market differentiation** but require harmonization to avoid duplication and inefficiencies; the large number of applicable schemes also adds complexity.

Aquafeed accounts for over 50% of production costs in fed aquaculture, making feed efficiency and price stability critical for the aquaculture sectors competitiveness. Employment in feed manufacturing remains significant, with major EU producers contributing to regional economies. However, dependency on imported raw materials—particularly soy and fish oil—poses risks to supply security, exacerbated by geopolitical tensions and climate variability.

Consumer preferences for sustainability and organic certification are reshaping market priorities, driving demand for traceable, responsibly sourced feeds. At the same time, societal concerns over GMOs and animal by-products influence formulation strategies and regulatory discourse with potentially sustainable and effective materials being discounted due to consumer preferences.

In conclusion, **the European aquafeed sector stands at a critical juncture.** Balancing growth with sustainability will require coordinated action across policy, industry, and research domains. The integration of innovative feed solutions, coupled with robust governance and stakeholder engagement, will be pivotal in securing a competitive, resilient, and environmentally responsible aquaculture industry for the future.

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7. Annex 1 – Additional information on project methodology

7.1. Data and information collection and analysis

Scientific literature and information were collected from recognised databases including Web of Science, Scopus, ResearchGate and Google Scholar. The searches for academic articles employed a combination of relevant search terms joined internally by “OR” operators and joined together using the “AND” operator. These search terms were searched for within the fields “Title-Abs-Key”, from Scopus and within the fields “TI”, “AB” and “AK”, from Web of Science.

For grey literature, project partners investigated the local sources available to them and employed similar search terms for the primary literature search, adapting these to local languages where required.

7.2. Stakeholder consultation

Expert stakeholders from across the aquafeed, aquafeed additive and aquafeed material sector were contacted and invited to participate in a stakeholder consultation. This consisted of an online stakeholder questionnaire (held on the LimeSurvey platform) ([109]) and a semi-structured online interview ([110]). The survey period was May – August 2025. Results were analysed using the R-Studio Statistical Programming Software tool ([111]).

7.2.1. Online survey questionnaire

The online survey landing page presented respondents with a background to the project, instructions and privacy policy details (Figure 37).

([109]) See https://www.limesurvey.org/

([110]) A total of 12 online interviews were conducted, with a total of 90 responses to the online survey (though this varied per question as not all respondents responded to all questions)

([111]) See https://www.r-project.org/

Figure 46 - Online survey landing page

Aquaculture Framework Contract Specific Contract No. 2: Study on feed for aquaculture – aquafeeds

Stakeholder survey questionnaire

Project background

Sustainable and secure aquafeed supply chains are imperative to meeting market demands and the development of a competitive and resilient aquaculture sector in the EU in line with the Strategic guidelines for a more sustainable and competitive EU aquaculture.

However, aquafeed supply chains face challenges: geopolitical conflicts impacting commodity prices and supply chain security; climate change impacts on reduction fishery and other material supply chain dynamics; and rising consumer demands and regulatory requirements for traceability and transparency.

This study aims to document and analyse the current status of the aquafeed, aquafeed materials and aquafeed additive sector for key species within European aquaculture across market and trade dynamics, alternative materials, environmental impacts, and supply chain traceability.

This survey is part of the European Commission project CINEA/EMFAF/2024/3.1/01/SC02/SI2.929372 Study on feed for aquaculture – aquafeed.

The survey should take approximately 15 minutes to complete.

Privacy statement

The results of this survey will be compiled and anonymised into a report such that it will not be possible for anyone outside of the consortium team to trace responses back to an individual, nor will your details and any personal information be shared with external parties. Further details regarding confidentiality and non-disclosure are provided in the attachment sent to you with the link for this survey.

Your contribution, while anonymised, is very appreciated and will add value to the project.

Respondents were asked to provide some background information about themselves (option to include name and email address), as well as selecting the most relevant stakeholder group to which they belonged. The stakeholder options were:

- Commercial Feed Company, Feed Producer, Feed Material Producer, Feed Additive Producer, Feed Solutions Company
- Farmer, Fish Producer, Fish Processor
- Government Authority, Competent Authority, Regulator, State Agency
- Industry Representative Group, Trade Association
- Non-Governmental Organisation, Advocacy Group
- Scientist/Research Body
- 3rd Party Certification & Standards Organisation
- Other

The survey was then divided into different question groups based on different aspects of the project. This included:

- Question group 1, which explored the extent to which the current policy and regulatory framework appropriately address the specific nuances of the aquafeed sector. Specific questions appeared depending on the type of stakeholder responding.
- Question group 2, which explored the aquafeed, aquafeed materials and aquafeed additive markets, with an emphasis on fishmeal and fish oil supply chains
- Question group 3, which explored the transparency of aquafeed, aquafeed material and aquafeed additive supply chains, as well as traceability tools.
- Question group 4, which explored alternative and emerging materials, with a focus on reducing inclusion levels of fishmeal, fish oil and soy.
- Question group 5 which explored environmental and social sustainability of the aquafeed supply chains.

7.3. Stakeholder workshop

A stakeholder workshop was held in October 2025 to present indicative results to a set of key stakeholders. These stakeholders included some of the consultees from the earlier stakeholder consultation period. The workshop was held remotely (via MS Teams) and made use of Mentimeter ([112]) and plenary discussions to present results to date and gather further insights, validation and opinions on the project’s draft findings.

([112]) See https://www.mentimeter.com/

8. Annex 2 - Inventory & description of key governing policy & regulatory frameworks, voluntary standards and 3rd party certification tools

8.1. International standards

8.1.1. Codex Alimentarius

Maintained by the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO), *Codex Alimentarius* sets international food standards, guidelines and codes of practice ([113]). Although technically a “soft law” instrument, it plays a key role in international trade as a reference document to the SPS Agreement.

The Codex Alimentarius Commission (Codex) was established on the basis of a resolution of the governing bodies of the Food and Agriculture Organization of the United Nations (FAO) in 1961 and the World Health Organization (WHO) in 1963. Its primary objectives are to protect consumer health and to ensure fair practices in food trade through the elaboration, harmonization and publication of food standards and other related texts ([114]).

These include: (a) a wide range of standards for individual foods (some 239 in total), which include Codex Standard 193-1995, and the Codex General Standard for Contaminants and Toxins in Food and Feed; (b) a detailed classification of foods and animal feeds; (c) 105 separate guidelines including CXG 80-201 - Guidelines on the Application of Risk Assessment for Feed, CXG 81-2013 - Guidance for Governments on Prioritizing Hazards in Feed and CXG 90-2017 - Guidelines on Performance Criteria for Methods of Analysis for the Determination of Pesticide Residues in Food and Feed; and (d) 58 separate codes of practice including three that are relevant to aquafeed including CXC 54-2004, the Code of Practice on Good Animal Feeding, CXC 62-2006, the Code of Practice for the Prevention and Reduction of Dioxin, Dioxins-like PCBs and non-Dioxin-like PCBs in Food and Feed and CXC 74-2014, and the Code of Practice for Weed Control to Prevent and Reduce Pyrrolizidine Alkaloid Contamination in Food and Feed.

([113]) The EU and the EU Member States are members of both FAO and WHO.

([114]) Vapnek, tuJ. & Spreij, M. Perspectives and guidelines on food legislation, with a new model food law FAO Legislative Study No. 87. FAO, Rome.

In particular, Codex Code of Practice on Good Animal Feeding establishes a feed safety system for food-producing animals that covers the whole food chain, taking into account relevant aspects of animal health and the environment in order to minimize risks to consumers’ health (the Code applies in addition to the principles of food hygiene already established by Codex).The objective of the Code is to help ensure the safety of food for human consumption through adherence to good animal feeding practice at the farm level and good manufacturing practices during the procurement, handling, storage, processing, and distribution of animal feed and feed materials for food producing animals. It applies to the production and use of all materials destined for animal feed and feed materials at all levels, whether produced industrially or on a farm including aquaculture.

It sets out a number of definitions, including definitions of “feed/feeding stuff”, “feed material”, “feed additive”, “medicated feed” and “undesirable substances”. Section 4 sets out “General principles and requirements” with provisions on feed materials, labelling, traceability/product tracing and record keeping of feed and feed materials, inspection and control procedures and health hazards associated with animal feed. Section 5 is concerned with the production, processing, storage, transport and distribution of feed and feed materials, while section 6 is concerned with their “on-farm” production and use, while section 7 addresses methods of sampling and analysis. While the code of practice is of general application to all types of farming activity it contains a number of specific references to aquaculture.

Further guidance on “Good practices for the feed sector Implementing the Codex Alimentarius Code of Practice on Good Animal Feeding” was published by FAO in 2020 ([115]).

In addition, Codex maintains a database of the Codex Maximum Residue Limits for Pesticides and Extraneous Maximum Residue Limits.

As noted above, the SPS Agreement recognizes Codex as the source of international standards for food safety, although standards that result in a higher level of sanitary protection may be applied (if there is a scientific justification). The TBT Agreement also recognizes Codex standards, although indirectly, by referring to “international standards”.

8.1.2. Aquatic Animal Health Code

The basic mandate of the World Organization for Animal Health (WOAH), which was set up in 1924 as the *Office International des Epizooties* (OIE), an

([115]) FAO and IFIF. 2020. Good practices for the feed sector – Implementing the Codex Alimentarius Code of Practice on Good Animal Feeding. FAO Animal Production and Health Manual No. 24. Rome. https://doi.org/10.4060/cb1761en

intergovernmental organization that has its headquarters in Paris, is to improve animal health by: (1) informing governments of the occurrence and course of animal diseases and of ways to control disease outbreaks; (2) coordinating international scientific research on the surveillance and control of animal diseases; and (3) facilitating the harmonization of regulations pertaining to trade in animals and animal products.

The main normative document of the WOAH relevant to aquaculture is the Aquatic Animal Health Code the 26th edition of which was adopted in 2024 ([116]).

The WOAH maintains lists of animal pathogens/diseases that meet certain criteria with regard to their consequences (pathogenicity and resulting socio-economic impacts), spread and diagnostics namely: "diseases notifiable to the WOAH", and "other significant diseases”. WOAH regularly updates the lists as such diseases, especially notifiable disease, are directly relevant to international trade.

WOAH Member Countries are required to report outbreaks of notifiable diseases to WOAH headquarters within 24 hours as well as new strains, changes in distribution, incidence, virulence, morbidity etc. Countries are subsequently also required to send periodic reports throughout presence and evolution of listed diseases as well as final report once the country zone or compartment becomes free of diseases (as well as other routine periodic reporting requirements).

The listing and information procedures under the Aquatic Animal Health Code provide the legal basis for countries to restrict and control imports in accordance with the SPS Agreement because, as described above, the WOAH is the standard setting body for aquatic animal health.

The Aquatic Animal Health Code states that a particular concern with regard to aquaculture feed is the risk that it can be a source of infectious disease in aquatic animals. This is because aquatic animals are often a principal material in aquatic animal feed and because the use of semi-processed, raw and live feed continues to be a common practice, the risk of disease transmission via feed should be addressed ([117]).

The purpose of chapter 4.9 of the Aquatic Animal Health Code, “Control of Pathogenic Elements in Aquatic Animal Feed”, is to address the transmission of infectious diseases of aquatic animals via feed to prevent entry and spread into

([116]) Available at: https://doc.woah.org/dyn/portal/digidoc.xhtml?statelessToken=zfw_HthxEKlyZL2_bnsYOttSotkzpfqWGIFnKBeBqMY=&actionMethod=dyn%2Fportal%2Fdigidoc.xhtml%3AdownloadAttachment.openStateless

([117]) Aquatic Animal Code, article 4.8.1.

a country, zone or compartment that is free from pathogenic agents of concern and it applies “to the production and use of all products destined for feed and feed materials whether produced commercially or on farm”. The detailed risk analysis principles set out in chapter 2.1 of the Aquatic Animal Health Code are to be applied and it is stated to be complementary to guidance provided by the Codex Code of Practice on Good Animal Feeding mentioned above.

After describing the responsibilities of “Competent Authority” (meaning the government body responsible for the implementation of the code in a given country), feed producers, owners and managers of aquaculture establishments as well as veterinarians, the code next makes clear that its focus is on the biological hazards that may be present in feed and feed materials, including pathogenic agents such as bacteria, viruses, fungi, and parasites, and not on chemical or physical hazards.

Article 4.9.5 specifies that aquafeed may be “contaminated with pathogenic agents present at the time of harvesting, transport, storage and processing of commodities used as feed materials” as well as “during manufacture, transport, storage and use”. It goes to provide that poor hygienic practices during processing and manufacture, transport and storage are potential sources of contamination with pathogenic agents and that aquatic animals may directly or indirectly exposed to pathogenic agents in feed.

Article 4.9.6., “Risk management” is set out in three parts on, the “Use of safe feed and feed materials”, the “Use of feed and feed materials from sources that may not be free from pathogenic agents of concern” and “Feed production”.

8.1.3. International Plant Protection Convention

The basic purpose of the International Plant Protection Convention, 1997 ([118]) (the IPPC) is to prevent the spread and introduction of pests of plants and plant products, and to promote appropriate measures for their control. The EU and all Member States are party to the IPPC. The IPPC contains a number of definitions including for ‘plants’ (‘living plants and parts thereof, including seeds and germplasm’) and ‘plant product (‘unmanufactured material of plant origin (including grain) and those manufactured products that, by their nature or that of their processing, may create a risk for the introduction and spread of pests’).

This is to be achieved through the establishment by each contracting party of an official national plant protection organization which among other matters is charged with the issuance of phytosanitary certificates, confirming that plant products and other regulated articles and consignments thereof are in

([118]) International Plant Protection Convention (New Revised Text) (With Annex). Rome, 17 November 1997. 2367 *UNTS* A-1963.

conformity with the certifying statements relating to the occurrence, outbreak and spread of pests.

Contracting parties can also require non-discriminatory quarantine measures for quarantine and regulated non-quarantine pests and can as regards imports regulate the entry of plants and plant products and other regulated articles including through the adoption of phytosanitary measures including as regards inspection, prohibition on importation, and treatment or may refuse entry or detain, or require treatment, destruction.

Pursuant to the IPPC a series of International Standards for Phytosanitary Measures (ISPMs) have been adopted by the Commission on Phytosanitary Measures (CPM), the governing body of the IPPC. There are currently 44 ISPMs in force as well as 29 Diagnostic Protocols and 39 Phytosanitary Treatments ([119]).

8.1.4. FAO Code of Conduct for Responsible Fisheries

The Code of Conduct for Responsible Fisheries (the “Code of Conduct”) ([24]), which was adopted during the 28th Session of the FAO Conference on 31 October 1995, is a voluntary agreement that is addressed not only to States, but also to “fishing entities, sub-regional, regional and global organizations, whether governmental or non-governmental, and all persons concerned with the conservation of fishery resources and management and development of fisheries, such as fishers, those engaged in processing and marketing of fish and fishery products and other users of the aquatic environment in relation to fisheries”.

The scope of the Code of Conduct is extremely broad. It encompasses almost all aspects of fisheries and aquaculture management, setting out generally agreed “principles and standards applicable to the conservation, management and development of all fisheries”. It also covers the “capture, processing and trade of fish and fishery products, fishing operations, aquaculture, fisheries research and the integration of fisheries into coastal area management”. While the term “fisheries” is expressed to include “aquaculture” the document also contains a number of specific references to the sector.

It is relevant to the issue of aquafeed not only in terms of what it says about aquaculture and aquafeed but also as regards the capture of wild fish for use in aquafeed.

([119]) Available at: https://assets.ippc.int/static/media/files/publication/en/2021/04/ISPM_List_En_2021-03-17.pdf

For example, while article 6, ‘General Principles’, calls, for States to “consider aquaculture … as a means to promote diversification of income and diet” it goes on to provide that in so doing, “States should ensure that resources are used responsibly and adverse impacts on the environment and on local communities are minimized.” Subsequently Article 9 on ‘Aquaculture Development’ sets out a number of important principles for the responsible development of aquaculture including through the promotion of efforts to improve the “selection and use of appropriate feeds, feed additives and fertilizers, including manures”.

The Code of Conduct has been followed up with a series of technical guidelines for responsible fisheries that set out in more detail how it is to be implemented. These include FAO Technical Guidelines for Responsible Fisheries No. 5, *Aquaculture Development* which has in turn been further developed in a series of supplements (see Box 1) two of which are explicitly concerned with aquafeed.

Box 1 – Supplements to *Aquaculture Development.* FAO Technical Guidelines for Responsible Fisheries No. 5

Good Aquaculture Feed Manufacturing Practice

Health Management for Responsible Movement of Live Aquatic Animals

Genetic Resource Management

Ecosystem Approach to Aquaculture

Use of Wild Fish as Feed in Aquaculture

Use of Wild Fishery Resources for Capture based Aquaculture

Aquaculture Governance and Sector Development

Recommendations for Prudent and Responsible Use of Veterinary Medicines in Aquaculture

Development

8.1.5. FAO Guidelines for Sustainable Aquaculture

The ‘Guidelines for Sustainable Aquaculture’ (‘GSA’) outline a set of voluntary guidelines, best practices and management frameworks that underpin the development of a sustainable aquaculture sector. The GSA, while covering all aspects of aquaculture, focuses particularly on feeds for aquaculture in chapter *5.4 Sustainable Feed*, outlining key actions for states and relevant stakeholders which include:

5.4.1 Develop and implement national or regional strategies for supply of quality aquaculture feed based on sustainably sourced materials, appropriate to the national production sectors.

5.4.2 Promote the development and use of sustainably sourced materials (from all sources) in feed formulations, striving to achieve affordable, safe and healthy feeds and encouraging an increase in feed performance and reduction in environmental impact.

5.4.3 Follow FAO technical guidance in the use of wild fish and fish by-products as aquafeed to prevent and, where not possible, minimize negative impacts on livelihoods, food security and the environment and to ensure they come from sustainably managed fisheries, without compromising safety and quality of aquaculture products.

5.4.4 Support the gradual reduction and improve the efficiency of the use of wild fish stocks as feed.

5.4.5 Support investment in research and innovation to identify alternative feed materials notably from local resources, with good nutritional value that optimize feed conversion rates while being environmentally and socially sustainable. These may include insects, algae, single-cell proteins, agriculture by-products and fish/ food processing wastes.

5.4.6 Promote feeding practices that avoid contamination by pathogens, parasites, heavy metals, antimicrobials (antibiotics, parasiticide, antifungal and antiviral medicines) and other substances potentially harmful to humans.

5.4.7 Engage with the feed industry to encourage the development and utilization of diversified and improved feeds that are precisely formulated and manufactured to meet the nutritional requirements of species and farmed types based on life cycle stage, genotype, environment and immune status, purpose of culture (food/seed). Such feeds should maintain or enhance product quality and the human health benefits of farmed aquatic foods.

5.4.8 Promote feeding strategies, feed management practices and production systems that ensure precision use of feeds and high conversion efficiency in aquaculture while contributing to reducing feed costs, feed waste and environmental pollution.

5.4.9 Develop systems to regulate the safe use of feed additives and support the development and safe use of natural feed materials or additives recognizing that feed materials and formulations may be proprietary trade information.

5.4.10 Encourage feed manufacturing waste reduction by optimizing production processes and practices and recycling of waste materials and improving storage conditions of feeds and feed materials to safeguard quality and guarantee a longer shelf life, including the use of eco-friendly packaging using recyclable or biodegradable materials.

8.2. EU policy & legal framework

8.2.1. Food and feed law

The core of the EU policy and regulatory framework for aquafeed, derives from the EU’s food safety policy. The EU’s competence in this area mainly derives from articles 168 and 169 of the Treaty on the Functioning of the European Union (TFEU) ([120]).

Among other matters, article 168 provides that a “high level of human health protection shall be ensured in the definition and implementation of all Union policies and activities”, requires the EU and the Member States to “foster cooperation with third countries and the competent international organisations in the sphere of public health” (which would include FAO and WHO) and provides that measures in the veterinary and phytosanitary fields which have as their direct objective the protection of public health are to be adopted by the European Parliament and the Council in accordance with the “ordinary procedure”.

Article 169(1) provides that in order to “promote the interests of consumers and to ensure a high level of consumer protection”, the EU must contribute to “protecting the health, safety and economic interests of consumers, as well as to promoting their right to information, education and to organise themselves in order to safeguard their interests”. The EU must contribute to these objectives through the adoption of measures under article 114 TFEU to complete the internal market as well as measures to support, supplement and monitor the policy pursued by the Member States which may in turn adopt more stringent consumer protection measures but only if these are compatible with the Treaties (and thus do not, for example, interfere the functioning of the internal market).

Most EU food legislation is contained in regulations adopted by the European Parliament and the Council, supplemented by subordinate legislation adopted

([120]) Consolidated version of the Treaty on the Functioning of the European Union (OJ C 326, 26.10.2012, p. 4).

by the European Commission in the form of delegated or implementing acts (hereafter described as “subordinate legislation”).

As noted in the introduction, there is no specific EU legislation on aquafeed. Instead aquafeed, is generally addressed in instruments are also concerned with the far larger terrestrial animal feed sector as well as pet feed.

Many instruments considered in this part have modified, often on numerous occasions. The analysis that follows is based on the most recent (consolidated) texts.

8.2.1.1. Regulation No. 178/2002, the General Food Law

Regulation No. 178/2002, the General Food Law ([121]), which was adopted in 2002, sets out the basic framework and requirements of food law in the EU. It is clearly relevant to the issue of aquafeed given that aquatic animal production in aquaculture is geared towards food production.

The aim of the General Food Law is to provide “the basis for the assurance of a high level of protection of human health and consumers' interest in relation to food, taking into account in particular the diversity in the supply of food including traditional products, whilst ensuring the effective functioning of the internal market” (article 1(1)).

To this end it lays down the general principles governing food and feed in general, and food and feed safety in particular, at EU and national level, establishes the European Food Safety Authority (EFSA) and lays down procedures for matters with a direct or indirect impact on food and feed safety (article 1(2)).

In terms of its scope, it applies to “all stages of production, processing and distribution of food and feed”, apart from domestic preparation and consumption (article 1(3)).

The General Food Law clearly distinguishes between “food”, which is defined in article 2 to mean “any substance or product, whether processed, partially processed or unprocessed, intended to be, or reasonably expected to be ingested by humans”, and “feed”, which is defined in article 3(4) to mean any “substance or product, including additives, whether processed, partially processed or unprocessed, intended to be used for oral feeding to animals”.

([121]) Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety (OJ L 31, 1.2.2002, p. 1).

Although the General Food Law contains no express reference to aquatic animals, the aquaculture sector or aquafeed, the ordinary meaning of the wording of article 3(4) means that it applies to aquafeed.

It follows too, that aquafeed is subject to the provisions of Chapter II, “General Food Law”, which applies to all stages of the production, processing and distribution of food but also to “feed produced for, or fed to, food- producing animals” (article 4(1)).

Section 1 sets out the “General principles of food law”. Article 5(1), “General Objectives”, re-states “the general objectives of ensuring a high level of protection of human life and health and the protection of consumers' interests” while providing that “the protection of animal health and welfare, plant health and the environment” are to be taken into account where appropriate. This means, in summary, animal welfare and environmental considerations are taken into consideration subject to the primary objectives of protecting human health and the interests of consumers.

Also to be taken “into consideration” as regards the development or adaptation of food law, are existing international standards and those about to be established, except where “such standards or relevant parts would be an ineffective or inappropriate means for the fulfilment of the legitimate objectives of food law or where there is a scientific justification, or where they would result in a different level of protection from the one determined as appropriate in” the EU (article 5(3)). Put another way, this provision provides that as a matter of EU law, stricter standards may be established with regard to food and feed, including aquafeed.

Subsequent articles address risk analysis (article 6), the precautionary principle (article 7), and the protection of consumer interests (article 8). Section 1A addresses risk communication (in terms of its objectives, general principles, and the requirement for a general plan), while Section 2 sets out principles of transparency (in terms of requirements for public consultation and the provision of information to the public).

Section 3, “General obligations of the food trade”, provides in article 11, feed imported into the EU for placing on the market must comply with the relevant requirements of EU food law or conditions recognised by the EU to be “at least equivalent thereto or, where a specific agreement exists between the Community and the exporting country, with requirements contained therein”. In other words, the equivalent level of protection may be recognized in, say, a trade agreement.

The term “placing on the market” is defined in article 3 to mean means “the holding of food or feed for the purpose of sale, including offering for sale or any other form of transfer, whether free of charge or not, and the sale, distribution, and other forms of transfer themselves”.

The export of feed must, in accordance with article 12, comply with EU food law unless otherwise “requested” by the authorities of the imported country or as established in the legislation and administrative procedures in force in that country, with a duty in other circumstances to notify the authorities of the importing country why feed that is not unsafe cannot be placed on the market in the EU. Feed exports must in addition comply with the provisions of any bilateral trade agreement between that third country and the EU.

Article 13 requires the EU and the Member States to contribute to the development and implementation of international food, feed and phytosanitary standards in order to promote consistency while at the same time ensuring that “the high level of protection” adopted in the EU is not reduce.

Section 4, which is entitled, “General requirements of food law”, sets out a number of specific obligations as regards food and feed. In particular, article 15(1) states the basic principle that feed must not be “placed on the market or on the market or fed to any food-producing animal if it is unsafe”.

In accordance with article 15(2), feed is to be “deemed to be unsafe for its intended use” if it is “considered to have an adverse effect on human or animal health” or if it will “make the food derived from food-producing animals unsafe for human consumption”.

Article 15(3) provides that if unsafe feed is identified in a batch, lot or consignment of food, the entire batch, lot or consignment will be deemed unsafe unless there is no evidence, following a detailed assessment that the remainder of the batch, lot or consignment is unsafe. Article 15(4) states that feed that complies with specific EU feed safety provisions is to be deemed to be safe as far as those provisions are concerned.

In accordance with article 15(5) the competent authorities of a Member States may take appropriate measures or restrict the placing on the market of feed where there are reasons to suspect that it is unsafe even though it confirms with relevant provisions, while article 15(6) empowers the Member states to adopt feed safety provisions at the national level in cases where no such provisions have been adopted at EU level provided they accord with the TFEU particularly as regards its provisions on the free movement of goods and the functioning of the customs union.

The remaining articles in Section 4 impose a number of duties relating to the commercial activities the feed sector. First, article 16 provides that the labelling, advertising and presentation of feed must not mislead consumers. including as regards the shape, appearance or packaging, the packaging materials used, the manner in which they are arranged and the setting in which they are displayed, as well as the information which is made available about them in whatever form.

Article 17 addresses “Responsibilities”. If first imposes a general duty on food and feed business operators to ensure that foods or feeds satisfy the requirements of food law which are relevant to their activities at all stages of production, processing and distribution within the businesses under their control and to verify compliance accordingly (article 17(1).

In this regard, the term “feed business” is broadly defined in article 3(5) to mean “any undertaking whether for profit or not and whether public or private, carrying out any operation of production, manufacture, processing, storage, transport or distribution of feed including any producer producing, processing or storing feed for feeding to animals on his own holding”.

A “feed business operator” is turn defined to mean “the natural or legal persons responsible for ensuring that the requirements of food law are met within the feed business under their control” (article 3(6)).

Article 17(2) goes on to impose a duty on the Member States to enforce EU food law, and “to monitor and verify that the relevant requirements of food law are fulfilled by food and feed business operators at all stages of production, processing and distribution”. To this end each Member State must maintain a system of “official controls”, as well as other appropriate activities including food and feed safety surveillance and other monitoring activities covering all stages of production, processing and distribution, and set out effective, proportionate and dissuasive measures penalties for non-compliance.

Article 18 sets out general obligations as regards traceability, which is defined in article 3(15) to mean “the ability to trace and follow a food, feed, food-producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution”.

More specifically, article 18(1) sets out the basic requirement that “the traceability of food, feed, food-producing animals, and any other substance intended to be, or expected to be, incorporated into a food or feed shall be established at all stages of production, processing and distribution”. In other words, as regards aquafeed, feed and additives must both be traceable throughout the supply chain up until final sale.

To this end aquafeed business operators must be able to identify any person from whom they have been supplied with feed or any substance intended to be, or expected to be, incorporated into a food or feed and must put in place systems and procedures to enable this information to be provided to the competent authorities on demand (article 18(2)) and to identify other businesses to which their products have been supplied (article 18(3)).

Feed that is placed on the market, or which. is likely to be placed on the market within the EU must be adequately labelled or identified to facilitate its traceability, through relevant documentation or information in accordance with

the relevant requirements of more specific provisions in accordance with article 18(4) with provision being made in article 18(5) for the adoption by the European Commission of subordinate legislation to this end.

Article 20 imposes a number of specific duties on feed business operators.

First, in accordance with article 20(1)) a feed business operator must immediately initiate procedures to withdraw feed from the market and inform the competent authorities accordingly, if that operator consider considers or has reason to believe that “a feed which it has imported, produced, processed, manufactured or distributed does not satisfy the feed safety requirements. In such a case that feed must be destroyed, in accordance with article 15(3) unless the competent authority is satisfied otherwise and the operator must “effectively and accurately inform users of the feed of the reason for its withdrawal, and if necessary, recall from them products already supplied when other measures are not sufficient to achieve a high level of health protection”.

A feed business operator that is responsible for retail or distribution activities that do not affect the packaging, labelling, safety or integrity of feed must, within the limits of its respective activities, initiate procedures to withdraw from the market products not in compliance with the feed-safety requirements and must also participate in contributing to the safety of food by passing on relevant information necessary to trace a feed, cooperating in the action taken by producers, processors, manufacturers and/or the competent authorities (article 20(2).

Moreover, a feed business operator must: immediately inform the competent authorities if it considers or has reason to believe that a feed which it placed on the market may not satisfy the feed safety requirements; inform them of the action taken to prevent risk arising from the use of that feed; and must not “prevent or discourage any person from cooperating, in accordance with national law and legal practice, with the competent authorities, where this may prevent, reduce or eliminate a risk arising from a feed” (article 20(3)).

Feed business operators must in any event collaborate with the competent authorities on action taken in order to avoid risks posed by a feed which they supply or have supplied (article 20(4)).

Finally, article 21 provides that the provisions of Chapter II, General Food Law, shall apply without prejudice to the requirements of the Defect Products Liability Directive ([122]).

([122]) Council Directive 85/374/EEC of 25 July 1985 on the approximation of the laws, regulations and administrative provisions of the Member States concerning liability for defective products (OJ L 210, 7.8.1985, p. 29).

Chapter III of the General Food Law is concerned with the Establishment of the European Food Safety Authority (EFSA) which is tasked with providing: “scientific advice and scientific and technical support” for EU legislation and policies in “all fields which have a direct or indirect impact on food and feed safety”, for providing independent information on all matters within these fields and communicating on risks. In other words, EFSA is the EU’s principal technical food and feed safety agency.

Much of the detail of Chapter III relates to the functioning of EFSA and its various bodies and is not directly relevant to aquafeed.

Chapter IV of the General Food Law is concerned with the Rapid Alert System, Crisis Management and Emergencies.

The Rapid Alert System, Food and Feed (RASFF) was established to ensure the exchange of information between Member States, the European Commission and the FSA to support swift reaction by food safety authorities in case of risks to public health resulting from the food chain. Where a member of the network has any information relating to the existence of a serious direct or indirect risk to human health deriving from food or feed, this information must immediately be notified to the Commission under the RASFF (article 50(2)). The RASFF provides a round-the-clock service to ensure that urgent notifications are sent, received and responded to collectively and efficiently. RASFF information is available on an online searchable database called the “RASFF Window” on the EC’s website ([123]). Information exchanged through RASFF can lead to products being recalled from the market.

Article 53 of the General Food Law provides for the adoption by the EC of emergency measures in case where food or feed originating from within the EU or imported from a third country is likely to constitute a serious risk to human health, animal health or the environment, and that such risk cannot be contained satisfactorily by means of measures taken by the Member State(s) concerned.

Depending on the gravity of the situation, in the case of food or feed originating within the EU, such measures may include the suspension of the placing on the market or use of the food or feed in question, laying down special conditions for that food or feed or any other interim measure. As regards food or feed imports these may be suspended from all or part of the exporting country or any transit country, subject to special conditions or any other appropriate interim measure.

In addition, a Member State may adopt interim protective measures in accordance with article 54 if, having informed the EC of the need to take emergency measures, the latter has not done so. The Member State concerned

([123]) Available at https://webgate.ec.europa.eu/rasff-window/screen/search.

must notify both the other Member Staes and the EC, which must put the matter before the Standing Committee on Plants, Animals, Food and Feed, established by the EC in accordance with article 58(1), and may maintain its national interim protective measures until measures are adopted at EU level.

In accordance with article 55, the EC must draw up a general plan for crisis management in the field of the safety of food and feed, in close cooperation with EFSA and the Member States, which must: specify the types of situations involving direct or indirect risks to human health deriving from food and feed which are not likely to be prevented, eliminated or reduced to an acceptable level by provisions in place or cannot adequately be managed solely by way of the application of Articles 53 and 54 as well as the practical procedures necessary to manage a crisis, including the principles of transparency to be applied and a communication strategy.

The EC must also notify the Member States and EFSA in cases where it identifies a situation involving a serious direct or indirect risk to human health deriving from food and feed, where the risk cannot be prevented, eliminated or reduced by existing provisions or cannot adequately be managed solely by way of the application of Articles 53 and 54 and set up a crisis unit with EFSA participation (article 56). This unit must collect and evaluate all relevant information and identify the options available to prevent, eliminate or reduce to an acceptable level the risk to human health as effectively and rapidly as possible and may request the assistance of any public or private person whose expertise to that end while also keeping the public informed of the risks involved and the measures taken.

Chapter V, “Procedures and final provisions” sets out the procedure whereby the EC may adopt subordinate legislation (article 57), addresses the establishment and functions of the Standing Committee on Plants, Animals, Food and Feed (articles 58 and 59), sets out a mediation procedure (article 60) and among other matters requires the periodic review of the General Food Law (article 61).

8.2.1.2. Directive No. 2002/32/EC, the Undesirable Substances in Animal Feed Directive

The Undesirable Substances in Animal Feed Directive ([124]), which was adopted after the General Food Law, addresses undesirable substances in products used for animal feed (article 1).

([124]) Directive 2002/32/EC of the European Parliament and of the Council of 7 May 2002 on undesirable substances in animal feed (OJ L 140, 30.5.2002, p. 10).

Article 3 sets out the basic requirement of the directive which is that products intended for animal feed may only be imported into the EU or put into circulation within the EU if they are “sound, genuine and of merchantable quality and therefore when correctly used do not represent any danger to human health, animal health or to the environment or could adversely affect livestock production”.

More concretely, products intended for animal feed are deemed not to be in conformity with this requirement if the level of contaminants they contain, which are described as “undesirable substances”, does not comply with the maximum levels laid down in Annex I of the directive. These contaminants include heavy metals, mycotoxins, inherent plant toxins, dioxins, PCBs and certain pesticides.

Although apparently straightforward on its face, article 3 is complicated by the fact a number of the basic terms that is used as are defined in article 2 as follows:

- “Products intended for animal feed” shall mean “feed materials, premixtures, additives, feedingstuffs and all other products intended for use or used in animal feed”.
- “Putting into circulation” or “circulation” shall mean the holding of products intended for animal feed for the purposes of sale, including offering for sale, or any other form of transfer, whether free or not, to third parties, and the sale or other forms of transfer themselves.
- “Undesirable substance” shall mean any substance or product, with the exception of pathogenic agents, which is present in and/or on the product intended for animal feed and which presents a potential danger to animal or human health or to the environment or could adversely affect livestock production.

Moreover, a number of terms used in the definitions are themselves defined in article 1. These include the definitions of

- “feedingstuffs” shall mean products of vegetable or animal origin, in their natural state, fresh or preserved, and products derived from the industrial processing thereof, and organic or inorganic substances, used singly or in mixtures, whether or not containing additives, for oral animal feeding.
- “feed materials” shall mean various products of vegetable or animal origin, in their natural state, fresh or preserved, and products derived from the industrial processing thereof, and organic or inorganic substances, whether or not containing additives, which are intended for use in oral animal feeding either directly as such or, after processing, in the preparation of compound feedingstuffs or as substrates for premixtures;

- premixtures’ shall mean mixtures of additives or mixtures of one or more additives with substances used as carriers, intended for the manufacture of feedingstuffs.
- ‘Compound feedingstuffs’ shall mean mixtures of feed materials, whether or not containing additives, which are intended for oral animal feeding as complete or complementary feedingstuffs.
- ‘Complementary feedingstuffs’ shall mean mixtures of feedingstuff which have a high content of certain substances and which, by reason of their composition, are sufficient for a daily ration only if used in combination with other feedingstuffs.
- ‘Complete feedingstuffs’ shall mean mixtures of feedingstuffs which, by reason of their composition, are sufficient for a daily ration.

In addition, the word “additives” is defined by reference to an earlier and now repealed instrument namely Council Directive 70/524/EEC of 23 November 1970 concerning additives in feeding-stuffs ([125]), which defined additives as “substances which, when incorporated in feeding-stuffs, are likely to affect their characteristics or livestock production”.

In other words, while the basic meaning of article 2 is rather dense, what is clear is that the scope of this directive is sufficiently broad to include aquafeed.

In accordance with article 4 of the directive, the Member States were required: to prescribe in their national legislation the undesirable substances listed in Annex I that may be tolerated in products intended for animal feed subject to the provisions of that Annex. The Member States are also required to investigate the sources of undesirable substances by reference the thresholds for investigations set out in Annex II and to report their findings to the EC.

In addition, Member State legislation must provide that the maximum levels fixed in the Annexes may not be mixed for dilution purposes with the same, or other, products intended for animal feed (Article 5) and must prescribe that in so far as there are no provisions on complementary feedingstuffs may not, taking into account the proportion prescribed for their use in a daily ration, contain levels of the undesirable substances listed in Annex I that exceed those fixed for complete feedingstuffs.

Article 7 empowers the Member States to provisionally reduce the existing maximum level, fix a maximum level or prohibit the presence of that undesirable substance in products intended for animal feed in cases where they have grounds, based on new information or a reassessment of existing information, to believe that a maximum level fixed in Annex I or an undesirable substance not listed therein present a danger to animal or human health or to the

([125]) OJ L 270, 14.12.1970.

environment and to promptly notify the European Commission accordingly. The Commission shall then make a decision as to whether or not the Annexes should be amended on the basis of subordinate legislation.

In accordance with article 8 the EC is required to adopt subordinate legislation to amend the annexes in the light of scientific and technical developments. The Commission may also define acceptability criteria for detoxification processes as a complement to the criteria provided for products intended for animal feed which have undergone such processes (Article 8(2)).

As this instrument is a directive it was required to be transposed into the national legislation of the Member States. The relevant transposition measures are set out on the Eurex ([126]).

8.2.1.3. Regulation No. 1829/2003 - the Genetically Modified Food and Feeds Regulation

The issue of genetically modified (GM) feed is addressed in Regulation No. 1829/2003, the Genetically Modified Food and Feeds Regulation ([127]). The objective of the regulation, set out in article 1, is to:

(a) provide the basis for ensuring a high level of protection of human life and health, animal health and welfare, environment and consumer interests in relation to genetically modified food and feed, whilst ensuring the effective functioning of the internal market in line with the General Food Law.

(b) lay down EU procedures for the authorisation and supervision of genetically modified food and feed.

(c) lay down provisions for the labelling of genetically modified food and feed.

A number of the general definitions are set out in article 2 are relevant to GM feed, including a definition of ‘genetically modified organism’ or ‘GMO’.

([126]) https://eur-lex.europa.eu/legal-content/EN/NIM/?uri=CELEX:32002L0032

[127] Regulation (EC) No 1829/2003 of the European Parliament and of the Council of 22 September 2003 on genetically modified food and feed (OJ L 268, 18.10.2003, p. 1).

This term is defined by reference to definition “O” in Article 2(2) of GMO Deliberate Release Directive ([128]) but excluding organisms obtained through the techniques of genetic modification listed in Annex I B of that directive.

The definition contained in article 2(2) is as follows: “an organism, with the exception of human beings, in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination”. To be included in the definition genetic modification must occur using one of the techniques listed in Annex I A, part 1 of that Directive while those techniques listed in Annex I A, part 2 are not considered to result in genetic modification. Techniques listed in Annex I A, part 1 include recombinant nucleic acid techniques, techniques involving the direct introduction into an organism of heritable material prepared outside the organism and cell fusion by means of methods that do not occur naturally. The techniques listed in Annex I B of that directive, and which are exempted from its scope are: (1) mutagenesis; and (2) cell fusion (including protoplast fusion) of plant cells of organisms which can exchange genetic material through traditional breeding methods.

The term ‘placing on the market’ is defined to mean “the holding of food or feed for the purpose of sale, including offering for sale, or any other form of transfer, whether free of charge or not, and the sale, distribution and other forms of transfer themselves”.

While Chapter II of the regulation is concerned with genetically modified food, the issue of genetically modified feed (GM feed), which is defined in article 2 to mean “feed containing, consisting of or produced from GMOs”, is addressed in Chapter III.

Chapter III is in turn divided into two sections, Section 1 on “Authorisation and Supervision” and Section 2 on “Labelling”.

Article 15(1) sets out the scope of Section 1 and provides that it applies to: (a) GMOs for feed use; (b) feed containing or consisting of GMOs; and (c) feed produced from GMOs (and the term “produced from GMOs” is defined in article 2 to means derived, in whole or in part, from GMOs, but not containing or consisting of GMOs).

This regulation is therefore potentially of relevance to the aquafeed sector in the context of the use in aquafeeds of GM grains and other cereals and indeed a number of GM grain products have been approved for use in feed over recent years (including maize and oilseed rape).

([128]) Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC - Commission Declaration (OJ L 106, 17.4.2001, p. 1).

Article 16(1) states that as a basic principle, GM feed must not: (a) have adverse effects on human health, animal health or the environment; (b) mislead the user; (c) harm or mislead the consumer by impairing the distinctive features of the animal products; (d) differ from feed which it is intended to replace to such an extent that its normal consumption would be nutritionally disadvantageous for animals or humans.

Moreover, in accordance with article 16(2) the placing on the market, use or processing of GM feed is prohibited unless it takes place in accordance with the conditions of an authorisation (article 16(2)) and such authorisation may be granted unless the applicant has “adequately and sufficiently demonstrated that it satisfies the requirements of article 16 (1)” (article 16(3)).

Article 16(4) clarifies that an authorisation under article 16(2) may cover: (a) a GMO and feed containing or consisting of that GMO as well as feed produced from that GMO; or (b) feed produced from a GMO as well as feeds produced from or containing that feed.

Subsequent articles:

- set out the procedure for applying for applying for an authorisation, which is to be submitted initially to the national competent authority of the Member State concerned and involves the issuance of a formal opinion by EFSA (articles 17 and 18) with a final decision being taken by the European Commission (article 19). If an authorisation is granted it is valid throughout the EU for a period of 10 years.
- address the status of existing products (article 20).
- set out requirements for supervision (article 21); and
- address the modification, suspension and revocation of authorisations (article 22) as well as their renewal (article 23).

Section 2 applies to the Labelling of GM feed, except in the case of feed “containing material which contains, consists of or is produced from GMOs in a proportion no higher than 0,9 per cent of the feed and of each feed of which it is composed, provided that this presence is adventitious or technically unavoidable”.

To establish this, an operator (defined in article 2 to mean means a “natural or legal person responsible for ensuring that the requirements of this Regulation are met within the food businesses or feed businesses under its control”) must supply evidence to satisfy the competent authorities that they have taken appropriate steps to avoid the presence of such materials.

Otherwise, in cases where this exemption does not apply, GM feed may not be “placed on the market” unless specified information is shown, “in a clearly visible, legible and indelible manner, on an accompanying document or, where

appropriate, on the packaging, on the container or on a label attached thereto” (article 25(2)).

In the case of GMOs for feed use and feed containing or consisting of GMOs, the words ‘genetically modified (name of the organism)’ must appear in parentheses immediately following the specific name of the feed (or alternatively, these words may appear in a footnote to the list of feed but in a font of at least the same size as that list). As regards feed produced from GMOs, the words ‘produced from genetically modified (name of the organism)’ must appear in parentheses immediately following the specific name of the feed (or alternatively, these words may appear in a footnote to the list of feed in a font of at least the same size as that list).

In addition, as specified in the authorisation the following characteristics must be indicated:

a) any characteristic of GM feed that is different from its conventional counterpart must be specified in terms of its; (i) composition; (ii) nutritional properties; (iii) intended use; (iv) implications for the health of certain species or categories of animals.
b) any characteristic or property where a feed may give rise to ethical or religious concerns must also be specified.
c) appropriate information about the nature or characteristics of the feed in cases where it does not have conventional counterpart.

Chapter IV of the regulation sets out a number of “Common provisions”. For example, article 27 provides that where a product is “likely to be used as both food and feed”, a single application under Articles 5 and 17 is to be submitted and this will in turn result in a single EFSA opinion and EC decision, with EFSA determining whether the “application for authorisation should be submitted both as food and feed”.

Article 28 provides for the establishment of a publicly accessible EU register of GM food and feed (available on the EC website ([129]) while article 29 requires EFSA to make information about applications for authorisation, together with relevant supporting information, supplementary information by applicants, as well as its scientific opinions available to the public subject to appropriate confidentiality restrictions (article 30) and provisions on the protection of scientific data (article 31).

In addition, where products authorised by or in accordance with Genetically Modified Food and Feeds Regulation are likely to constitute a serious risk to human health, animal health or the environment, article 34 provides for the

([129]) https://food.ec.europa.eu/plants/genetically-modified-organisms/gmo-register_en),

exercise of the emergency procedures provided for in articles 53 and 54 of the General Food Law.

8.2.1.4. Regulation No. 1830/2003 – GMO Food and Feed Traceability and Labelling Regulation

The objective of Regulation No. 1839/2003, the GMO Food and Feed Traceability and Labelling Regulation ([130]), is to “provide a framework for the traceability of products consisting of or containing GMOs, and food and feed produced from GMOs, with the objectives of facilitating accurate labelling, monitoring the effects on the environment and, where appropriate, on health, and the implementation of the appropriate risk management measures including, if necessary, withdrawal of products” (article 1).

It applies *inter alia* to GM feed placed on the market in accordance with the Genetically Modified Food and Feeds Regulation (article 2). While a number of definitions are set out in article 3, including a definition of traceability (“the ability to trace GMOs and products produced from GMOs at all stages of their placing on the market through the production and distribution chains”), Article 4 sets out traceability and labelling requirements for products consisting of or containing GMOs and is set out in three parts, Part A. Traceability and Part B. Labelling and Part C. Exemptions

Part A of article 4 provides that at the first stage of the placing on the market of a product consisting of or containing GMOs, including bulk quantities, operators shall must ensure that information is transmitted in writing to the operator receiving the product to the effect that that the product contains or consists of GMOs and a unique identifier assigned to those GMOs in accordance with article 8 of the regulation.

There are two points to note here. First, the term ‘the first stage of the placing on the market of a product’ is defined in article 1 of the regulation to mean “the initial transaction in the production and distribution chains, where a product is made available to a third party”. In other words, this duty arises as the outset of the commercial process.

Second, article 8 of the regulations provides for the Commission to adopt subordinate legislation to establish and adapt a system for the development and assignment of unique identifiers to GMOs taking account of developments in international fora. Thereafter, at all subsequent stages of the placing on the

([130]) Regulation (EC) No 1830/2003 of the European Parliament and of the Council of 22 September 2003 concerning the traceability and labelling of genetically modified organisms and the traceability of food and feed products produced from genetically modified organisms and amending Directive 2001/18/EC (OJ L 268, 18.10.2003, p. 24).

market of such products, operators must ensure that this information, including the unique identifier, is transmitted in writing to operators receiving the products.

In the case of products consisting of or containing mixtures of GMOs to be used only and directly as feed or for processing, the information referred to in paragraph 1(b) may be replaced by a declaration of use by the operator, accompanied by a list of the unique identifiers for all those GMOs that have been used to constitute the mixture.

Operators must have in place systems and standardised procedures to allow the holding of information and the identification, for a period of five years from each transaction, of the operator by whom and the operator to whom the products referred to in paragraph 1 have been made available.

Part B. of article 4, “Labelling” requires to operators to ensure that: (a) in the case of pre-packaged products consisting of, or containing GMOs, the words ‘This product contains genetically modified organisms’ or that ‘This product contains genetically modified [name of organism(s)]’ must appear on a label; while (b) in the case of non-pre-packaged products containing GMOs offered to the final consumer the words ‘This product contains genetically modified organisms’ or ‘This product contains genetically modified [name of organism(s)]’ must appear on, or in connection with, the display of the product.

Part C. of article 4, “Exemptions”, provides that: (1) the labelling requirements in Parts A. and B. of the article do not apply to traces of GMOs in products in a proportion no higher than the thresholds established in accordance with the GMO Deliberate Release Directive and in other specific EU legislation, provided that such traces of GMOs are adventitious or technically unavoidable; and (2) that Parts A and B. do not apply to traces of GMOs in products intended for direct use as food, feed or for processing in a proportion no higher than the thresholds established for those GMOs in accordance with the Genetically Modified Food and Feeds Regulation, provided that such traces of GMOs are adventitious or technically unavoidable.

Article 5, sets out traceability requirements for food and feed products produced from GMOs by requiring operators, when placing such on the market, to ensure that the following information is transmitted in writing to the operator receiving the product:

a) an indication of each of the food materials which is produced from GMOs.
b) an indication of each of the feed materials or additives which is produced from GMOs.
c) in the case of products for which no list of materials exists, an indication that the product is produced from GMOs.

In addition, operators must have systems and standardised procedures in place to allow the holding of the information specified the previous paragraph and the identification, for a period of five years from each transaction, of the operator by whom and to whom those products have been made available, with an exemption for traces of GMOs in line with thresholds mentioned above.

Article 6 sets out a number of exemptions in certain specified circumstances while article 7 amends the GMO Deliberate Release Directive to address the exemption of unavoidable trace elements.

Article 8 empowers the EC to adopt subordinate legislation to establish and adapt a system for the development and assignment of unique identifiers for GMOs taking account of developments in international fora. Such a regulation was adopted in 2004 ([131]).

Article 9 imposes a duty on the Member States to ensure that inspections and other control measures including sample checks and testing (qualitative and quantitative), as appropriate, are carried out to ensure compliance with the regulation.

8.2.1.5. Regulation No. 1831/2003 – the Feed Additives Regulation

The purpose of Regulation No. 1831/2003, the Feed Additives Regulation ([132]) is to establish a Union procedure for authorising the placing on the market and use of feed additives and to lay down rules for the supervision and labelling of feed additives and premixtures in order to achieve the objectives of the General Food Law.

While the definitions of ‘feed’, ‘feedingstuff’, ‘feed business’, ‘feed business operator’, ‘placing on the market’ and ‘traceability’ set out in the General Food Law, a number of additional definitions are set out in article 2, including a definition of ‘feed additive’.

The term “feed additive” is defined to mean “substances, micro-organisms or preparations, other than feed material and premixtures, which are intentionally added to feed or water in order to perform, in particular, one or more of the functions mentioned in Article 5(3)” of the regulation.

([131]) Commission Regulation (EC) No 65/2004 of 14 January 2004 establishing a system for the development and assignment of unique identifiers for genetically modified organisms (OJ L 10, 16.1.2004, p. 5).

([132]) Regulation (EC) No 1831/2003 of the European Parliament and of the Council of 22 September 2003 on additives for use in animal nutrition (OJ L 268, 18.10.2003, p. 29).

These functions are that the additive: (a) favourably affects the characteristics of feed; (b) favourably affects the characteristics of animal products; (c) favourably affects the colour of ornamental fish and birds; (d) satisfies the nutritional needs of animals, (e) favourably affects the environmental consequences of animal production; (f) favourably affects animal production, performance or welfare, particularly by affecting the gastro-intestinal flora or digestibility of feedingstuffs: or (g) have a coccidiostatic or histomonostatic effect (defined in article 2 to mean that they kill or inhibit protozoa).

Article 3(1) sets out the core legal requirement of the regulation which is that no person may place on the market, process or use a feed additive unless: (a) that additive it is covered by an authorisation granted in accordance with the regulation; (b) the conditions for use set out in the regulation, including the general conditions set out in its Annex IV are satisfied (unless otherwise provided for in the authorisation); (c) the labelling requirements of the regulation have been met.

Article 3 goes on to provide certain limited exceptions for scientific research while also imposing additional restrictions on the first placing on the market of certain categories of additive, while allowing the mixing of additives to be sold directly to an end-user, subject to compliance with the conditions for use laid down in the authorisation for each single additive.

Article 4 provides that an application for an authorisation for a feed additive or for a new use of a feed additive shall be submitted in accordance article 7, that an authorisation shall not be granted, refused, renewed, modified, otherwise than accordance with the articles 53 and 54 of Regulation No. 178/2002, the General Food Law that applicant for an authorisation or its representative must be established in the EU.

For an additive to be authorised it must satisfy the requirements of article 5(2) while at the same time meet one or more the functions set out in article 5(3) as described above. Article 5(2) states that an additive must not: “(a) have an adverse effect on animal health, human health or the environment; (b) be presented in a manner which may mislead the user; or (c) harm the consumer by impairing the distinctive features of animal products or mislead the consumer with regard to the distinctive features of animal products”.

Article 6 provides that feed additives must be allocated to one or more of the following categories of additive group, depending on their functions and properties:

a) technological additives: any substance added to feed for a technological purpose.
b) sensory additives: any substance, the addition of which to feed improves or changes the organoleptic properties of the feed, or the visual characteristics of the food derived from animals.

c) nutritional additives.
d) zootechnical additives: any additive used to affect favourably the performance of animals in good health or used to affect favourably the environment.
e) coccidiostats and histomonostats.

In addition, within these categories, feed additives must be further allocated into one or more of the functional groups set out in Annex I to the regulation, according to their principal function or functions. A separate list of functional groups is listed in Annex I under each additive group, and the Commission is empowered to adopt subordinate legislation to feed additive categories and functional groups as a result of technological progress or scientific development.

In accordance with article 7, applications for authorisations for food additives are to be submitted to the EC which must promptly inform the Member States and EFSA. The minimum contents of applications and subsequent procedural requirements are then set out. Article 8 requires EFSA to provide its formal opinion on each application while article 9 for the authorisation of food additives to take place on the basis of a regulation adopted by the EC with the deadlines and procedures for this and the minimum content of authorisations also being set out.

Subsequent articles address the status of existing products (article 10), the phasing out of the use of coccidiostats and histomonostats as feed additives (article 11), supervision (article 12), the modification, suspension and revocation of authorisations (article 13), the renewal of authorisations (article 14) and urgent applications (article 15).

Article 16, which is the sole article in Chapter III of the regulation, prohibits the placing on the market of any a feed additive or a premixture of additives unless its packaging or container is labelled the following information, in a conspicuous, clearly legible and indelible manner, in at least the national language or languages of the Member State, with the following information in relation to each additive contained in the material must be indicated:

a) the specific name given to the additives upon authorisation, preceded by the name of the functional group as mentioned in the authorisation.
b) the name or business name and the address or registered place of business of the person responsible for the product.
c) the net weight or, in the case of liquid additives and premixtures, either the net volume or the net weight.
d) where appropriate, the approval number of the establishment manufacturing or placing on the market the feed additive or the

premixture pursuant to Article 10 of the General Food Law and Feed Hygiene Regulation.

e) directions for use, and any safety recommendations regarding the use and, where applicable, the specific requirements mentioned in the authorisation, including animal species and categories for which the additive or premixture of additives is intended.
f) the identification number.
g) the batch reference number and date of manufacture.

Certain additional requirements are also specified for flavouring compounds, additional information regarding certain functional groups of additives, premixtures and marketing requirements regarding packages/containers.

Among matters addressed in Part IV of the regulation, “General and Final Provisions”, is the requirement for the establishment of a publicly accessible “Community Register of Feed Additives” (article 17), and provisions on transparency and confidentiality (article 18), administrative review (article 19), data collection (article 20), the establishment of the Community Reference Laboratory and its duties and tasks in accordance with Annex II, as well as powers conferred on the EC to adopt subordinate legislation.

Detailed provisions on the implementation of the Feed Additives Regulation are set out in subordinate legislation ([133]) which has also been used by the EC to approve an extensive list of feed additives, some of which are explicitly relevant to aquafeed ([134]).

A recent evaluation of the regulation, based on the five evaluation criteria of the Better Regulation Guidelines[135], found that while it has generally functioned well, and that its objectives remain relevant, more could be done to: (1) encourage innovation in feed additives, in particular those that can improve the sustainability of livestock farming; (2) reduce administrative and regulatory burden generated by the authorisation process; and (3) further enhance animal welfare ([136]).

([133]) For example, Commission Regulation (EC) No 429/2008 of 25 April 2008 on detailed rules for the implementation of Regulation (EC) No 1831/2003 of the European Parliament and of the Council as regards the preparation and the presentation of applications and the assessment and the authorisation of feed additives (OJ L 133, 22.5.2008, p. 1)

([134]) Commission Implementing Regulation (EU) 2024/1755 of 25 June 2024 concerning the authorisation of acetic acid, calcium acetate and sodium diacetate as feed additives for fish (OJ L, 2024/1755, 26.6.202),

([135]) European Commission, COMMISSION STAFF WORKING DOCUMENT Better Regulation Guidelines. Brussels, 3.11.2021, SWD(2021) 305 final.

([136]) https://food.ec.europa.eu/document/download/45adef94-ccb4-4a81-a013-5cadf8fe8d09_en?filename=animal-feed_additives_eval-legis_reg-2003-429_swd_2024-47_exec-sum.pdf

8.2.1.6. Regulation No. 183/2005, the Feed Hygiene Regulation

Regulation No. 183/2005, the Feed Hygiene Regulation ([137]) sets out (a) general rules on feed hygiene; (b) conditions and arrangements ensuring traceability of feed; (c) conditions and arrangements for registration and approval of establishments (article 1).

In terms of its scope, it applies to a) the activities of feed business operators at all stages, from and including primary production of feed, up to and including, the placing of feed on the market; (b) the feeding of food-producing animals; and (c) imports and exports of feed from and to third countries.

Article 4 imposes a general obligation on feed business operators (defined in article 3 to mean a natural or legal person responsible for ensuring that the requirements of the regulation are met with regard to the feed business under that person’s control) to ensure “that all stages of production, processing and distribution under their control are carried out in accordance with EU legislation, national law compatible therewith, and good practice”. Such operators must in particular ensure that they satisfy the relevant hygiene requirements laid down in the regulation.

More specific obligations are set out in article 5. In accordance with article 5(1), feed business operators operating at the level of “primary production” together with the following associated operations namely, (a) transport, storage and handling of primary products at the place of production, (b) transport operations to deliver primary products from the place of production to an establishment and (c) mixing of feed, for the exclusive requirements of their own holdings, without using veterinary medicinal products or additives or premixtures of additives, with the exception of silage additives, must comply as relevant with the requirements of Annex I to the regulation. Annex I sets out a relatively detailed list of requirements regarding hygiene and record keeping while also setting out matters to be addressed in national and EU guides on good practices for the control of hazards in primary production of feed.

For all other feed related business operations, feed business operators must comply with the requirements of Annex II. Annex II, which is substantially longer than Annex I, sets out a number of definitions and contains a detailed set of requirements under the following headings: facilities and equipment; personnel; production, quality control; dioxin monitoring for oils, fats and derived products; storage and transport; record keeping; and complaints and product recall.

([137]) Regulation (EC) No 183/2005 of the European Parliament and of the Council of 12 January 2005 laying down requirements for feed hygiene (OJ L 35, 8.2.2005, p. 1).

Article 5(3) also imposes a duty on feed business operators to (a) comply with specific microbiological criteria (not specifically defined or established under Regulation No. 183/2005); (b) take measures or adopt procedures necessary to meet specific targets as determined by the EC on the basis of subordinate legislation. In order to comply with their obligations under the regulation, article 5(4) provides that feed business operators may use the guides provided for in Chapter III of the regulation, while article 5(6) provides that feed business operators must only source and use feed from establishments which are registered and/or approved in accordance with the regulation.

Article 6(1) requires feed business operators carrying out operations other than those referred to in Article 5(1) to put in place, implement and maintain, a permanent written procedure or procedures based on the hazard analysis and critical control points (HACCP) principles set out in article 6(2). Article 6(2) states:

The principles referred to in paragraph 1 are the following:

a) identify any hazards that must be prevented, eliminated or reduced to acceptable levels;
b) identify the critical control points at the step or steps at which control is essential to prevent or eliminate a hazard or reduce it to acceptable levels;
c) establish critical limits at critical control points which separate acceptability from unacceptability, for the prevention, elimination or reduction of identified hazards;
d) establish and implement effective monitoring procedures at critical control points;
e) establish corrective action when monitoring indicates that a critical control point is not under control;
f) establish procedures to verify that the measures outlined in points (a) to (e) are complete and working effectively. Verification procedures shall be carried out regularly;
g) establish documents and records commensurate with the nature and size of the feed businesses to demonstrate the effective application of the measures set out in points (a) to (f).

Such procedures must be reviewed by the feed business operator when any modification is made in a product, process or any stage of production, processing, storage and distribution, the necessary changes must be made. Guides on the implementation of HACCP developed in accordance with article 20 of the regulation may be used while facilitation measures including for small businesses are also provided for.

Article 7 requires feed business operators to provide the relevant (national) competent authority with evidence of their compliance with Article 6 in the form

requested by that authority and to ensure that HACCP documentation is updated at all times. Powers are conferred on the EC to adopt subordinate legislation to for the implementation of article 7.

Article 8 provides for the adoption of subordinate legislation on financial guarantees as well as requirement that feed business operators of the type described in article 5(2) provide proof that they are covered by such guarantees.

A general duty on feed business operators to cooperate with the competent authorities is set out in Article 9(1), while article 9(2) requires such operators to notify the appropriate competent authority of any relevant establishments under their control in the required form prior to registration and to provide up to date information regarding such an establishment including as regards any changes in activity or it closure. In addition, the competent authority is required to maintain a register or registers of establishments (article 9(3)).

Article 10 requires feed business operators to ensure that establishments under their control and subject to the regulation are approved by the competent authority, in cases where: (1) such an establishment manufactures feed additives, or premixtures using feed additives or compound feedingstuffs using feed additives or premixtures containing feed additives or places them on the market; or (2) where approval is required under the national law of the Member State concerned; or (3) approval is required in accordance with subordinate legislation.

Article 11 prohibits feed business operators from operating unless they are registered in accordance with article 9 or approved in accordance with article 10.

Subsequent provisions: require Member States requiring approval under article 10(2) to inform the EC and the other Member States of the relevant national rules (article 12); set out he procedure and conditions for the approval by Member States of establishments (article 13); the suspension of registration or approval (article 14); the revocation of registration or approval (article 15); amendments to the registration or approval of an establishment (article 16); exemptions from on-site visits (article 17); transitional measures (article 18); and the preparation by competent authorities of lists of registered and approved establishments (article 19)

CHAPTER III of the regulation contains relatively detailed provisions on guides to good practice that may be adopted at EU or national level and the procedure for their development.

CHAPTER IV, on imports and exports, provides in effect in article 23 that feed businesses may only import feed from establishments in third countries if that country or that establishment is included on an EU approved list of countries on

the basis of EU standards or equivalent standards including in the case of a specific agreement between the EU and that country.

Article 24 sets out a number of interim measures.

Final provisions are set out in Chapter V and include a provision in article 29 that should a specific feed present a serious risk to human or animal health or to the environment, Article 50 of Regulation (EC) No 178/2002 shall apply mutatis mutandis.

8.2.1.7. Regulation No. 396/2005, the Pesticides Residue Regulation

Regulation No. 396/2005, the Pesticides Residue Regulation ([138]) sets out provisions relating to maximum levels of pesticide residues in or on food and feed of plant and animal origin (article 1). It applies to products of plant and animal origin, or parts thereof covered by Annex I to be used as fresh, processed and/or composite food or feed in or on which pesticide residues may be present. It applies to a number of oilseeds and cereals of the type used in aquafeeds as well as to fish and fish products.

A number of definitions are set out in article 3 including

- ‘pesticide residues’ means residues, including active substances, metabolites and/or breakdown or reaction products of active substances currently or formerly used in plant protection products as defined in Article 2, point 1 of Directive 91/414/EEC, (which is now repealed and replaced with Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC OJ L 309, 24/11/2009, p. which are present in or on the products covered by Annex I to this Regulation, including in particular those which may arise as a result of use in plant protection, in veterinary medicine and as a biocide;
- ‘Maximum residue level’ (MRL) means the upper legal level of a concentration for a pesticide residue in or on food or feed set in accordance with this Regulation, based on good agricultural practice and the lowest consumer exposure necessary to protect vulnerable consumers.

([138]) Regulation (EC) No 396/2005 of the European Parliament and of the Council of 23 February 2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin and amending Council Directive 91/414/EEC (OJ L 70, 16.3.2005, p. 1).

- ‘CXL’ means an MRL set by the Codex Alimentarius Commission.

Article 4 provides that the products for which MRLs are to apply are defined and covered in Annex I while active substances of approved plant protection products for which no MRLs are required are set out in Annex II.

Chapter II sets out a detailed procedure for the application for MRLs including as regards the submission of applications for MRLs, the consideration of such applications by EFSA and the setting modification or deletion of MRLs. In determining MRLs the review process generally follows CXLs except in cases where these are considered to be an ineffective or inappropriate means of fulfilling the EU’s objectives in terms, for example of consumer protection, or where there is a scientific justification for not doing so or where they would result in a different level of protection from that determined as appropriate in the EU.

Chapter III is concerned with MRLs applicable to products of plant and animal origin. Article 18(1) provides that the products covered by Annex I shall not contain, from the time they are placed on the market as food or feed, or fed to animals, any pesticide residue exceeding:

(a) the MRLs for those products set out in Annexes II and III.

(b) 0,01 mg/kg for those products for which no specific MRL is set out in Annexes II or III, or for active substances not listed in Annex IV unless different default values are fixed for an active substance while taking into account the routine analytical methods available. Such default values shall be listed in Annex V.

In accordance with article 18(2), Member States may not prohibit or impede the placing on the market or the feeding to food-producing animals within their territories of the products covered by Annex I on the grounds that they contain pesticide residues provided that: (a) such products comply with paragraph 1 and Article 20; or (b) the active substance is listed in Annex IV. Derogations for temporary higher residue levels in certain restricted circumstances (article 18(3)) or in exceptional (and limited) circumstances (article 18(4)).

The processing or mixing of products for dilution purposes is prohibited by article 19, while article 20 provides that where MRLs are not set out in Annexes II or III for processed and/or composite food or feed, the MRLs applicable shall be those provided in Article 18(1) for the relevant product covered by

Annex I, taking into account changes in the levels of pesticide residues caused by processing and/or mixing. In addition, specific concentration or dilution factors for certain processing and/or mixing operations or for certain processed and/or composite products may be included in the list in Annex VI.

MRLs for all crops and all pesticides are set out on the EU Pesticides Database (available at https://food.ec.europa.eu/plants/pesticides/eu-pesticides-database_en),

Chapter IV is concerned with the introduction of the MRL regime while Chapter V, on Official Controls, Reports and Sanctions has been largely repealed, for reasons that will become clear below.

The Pesticides Residue Regulation has been amended some 248 times (most recently on 12 May 2035) mostly as regards the Annexes. At 3,988 pages long it is one of the longest EU legislative instruments, almost entirely due to the length of the annexes (which in turn is due to the number of amendments).

8.2.1.8. Regulation No. 767/2009, the Feed Marketing and Use Regulation

The objective of Regulation No. 767/2009, the Feed Marketing and Use Regulation ([139]) is to “harmonise the conditions for the placing on the market and the use of feed” in line with the objectives and principles of the General Food Law (article 1).

In terms of its scope, it applies to all types of animal feed including feed for non-food producing animals (article 2). While a number of new definitions are set out in article 3, as will be seen below, the definitions of ‘feed’, ‘feed business’, and ‘placing on the market’ are those from the General Food Law, the definitions of ‘feed additive’, ‘premixture’, ‘processing aids’ and ‘daily ration’ are those form the Feed Additives Regulation while the definitions of ‘establishment’ and ‘competent authority’ are as set out in the Feed Hygiene Regulation.

The principal policy statement in the regulation is set out in article 4(1) which provides that feed may only be placed on the market and used if: (a) it is safe; and (b) if it does not have an adverse effect on the environment or animal welfare.

Moreover, feed business operators placing feed on the market must ensure that such feed: (a) is sound, genuine, unadulterated, fit for its purpose and of merchantable quality; and (b) is labelled, packaged and presented in accordance with the provisions laid down in the regulation and other applicable

([139]) Regulation (EC) No 767/2009 of the European Parliament and of the Council of 13 July 2009 on the placing on the market and use of feed, amending European Parliament and Council Regulation (EC) No 1831/2003 and repealing Council Directive 79/373/EEC, Commission Directive 80/511/EEC, Council Directives 82/471/EEC, 83/228/EEC, 93/74/EEC, 93/113/EC and 96/25/EC and Commission Decision 2004/217/EC (OJ L 229, 1.9.2009, p. 1).

EU legislation (article 4(2)). And in addition, feed must comply with the technical provisions on impurities and other chemical determinants set out in Annex I.

Article 5, provides that the person responsible for the labelling of feed must make available to the competent authorities any information concerning the composition or claimed properties of the feed placed on the market by that person, which allows the accuracy of the information given by the labelling to be verified, including the exact percentages by weight of feed materials (defined in article 3(2) as “products of vegetable or animal origin, whose principal purpose is to meet animals’ nutritional needs, in their natural state, fresh or preserved, and products derived from the industrial processing thereof, and organic or inorganic substances, whether or not containing feed additives, which are intended for use in oral animal-feeding either directly as such, or after processing, or in the preparation of compound feed, or as carrier of premixtures”) used in compound feed (which term is defined in article 3(2) to mean “a mixture of at least two feed materials, whether or not containing feed additives, for oral animal-feeding in the form of complete or complementary feed”).

The competent authority may, in the event of any “urgency relating to human or animal health or to the environment and without prejudice” to relevant EU intellectual property and having balanced the respective legitimate interests of the manufacturers and the purchasers, provide such information to a purchaser on the basis of a confidentiality clause if considered appropriate.

In accordance with article 6, feed may not contain or consist of the prohibited (or restricted) materials listed in Annex III, with powers conferred on the EC to vary this list from time to time, including through an emergency procedure if necessary.

Chapter 3 of the regulation is concerned with the placing on the market of different types of feed and confers power on the EC to adopt guidelines clarifying the distinction between feed materials, feed additives and other products such as veterinary drugs and, where necessary, to adopt measures in order to clarify whether a certain product constitutes feed for the purposes of the regulation (article 7).

Article 8(1) addresses the content of feed additives. It provides that the respective feed additive, feed materials and complementary feed shall not contain levels of feed additives that are higher than 100 times the relevant fixed maximum content in complete feed or five times in case of *coccidiostats* and *histomonostats*.

While the term “feed additive” bears the definition set out in the General Food Law, the Feed Additives Regulation, defines “feed materials” in article 3 to mean “products of vegetable or animal origin, whose principal purpose is to meet animals’ nutritional needs, in their natural state, fresh or preserved, and

products derived from the industrial processing thereof, and organic or inorganic substances, whether or not containing feed additives, which are intended for use in oral animal-feeding either directly as such, or after processing, or in the preparation of compound feed, or as carrier of premixtures”, while ‘complementary feed’ is defined to mean ‘compound feed which has a high content of certain substances but which, by reason of its composition, is sufficient for a daily ration only if used in combination with other feed”.

Article 8(2) goes on to provide that “the level of 100 times the relevant fixed maximum content in complete feed referred to in paragraph 1 may only be exceeded if the composition of the products concerned fulfils the particular nutritional purpose in respect of the relevant intended use under Article 10” of the regulation.

Article 9 provides that feed intended for particular nutritional purposes may only be marketed as such if its intended use is included in the list of intended uses established in accordance with Article 10 which in turn provides for the EC to update the list of intended uses set out in Commission Directive 2008/38/EC ([140]). However, while that directive has since been repealed and replaced with Commission Regulation (EU) 2020/354 ([141]) the latter instrument is restricted in its scope to the needs of terrestrial animals and has no relevance to aquafeed.

Chapter IV of the regulation contains relatively detailed provisions on feed labelling, presentation and packaging. Article 11(1) provides that labelling and the presentation of feed must not mislead the user, in particular:

a) as to the intended use or characteristics of the feed, in particular, the nature, method of manufacture or production, properties, composition, quantity, durability, species or categories of animals for which it is intended.
b) by attributing to the feed effects or characteristics that it does not possess or by suggesting that it possesses special characteristics when in fact all similar feeds possess such characteristics; or
c) as to the compliance of the labelling with the Community Catalogue and the Community Codes referred to in Articles 24 and 25.

Where feed materials or compound feed is marketed in bulk or in unsealed packages or containers, article 11(2) provides that it must be accompanied by a document containing all mandatory labelling particulars required under the regulation, while article 11(3) contains specific provisions relating to consumer

([140]) Commission Directive 2008/38/EC of 5 March 2008 establishing a list of intended uses of animal feedingstuffs for particular nutritional purposes (OJ L 62, 6.3.2008, p. 9).

([141]) Commission Regulation (EU) 2020/354 of 4 March 2020 establishing a list of intended uses of feed intended for particular nutritional purposes and repealing Directive 2008/38/EC (OJ L 67, 05/03/2020, p. 1).

protection legislation which are not relevant to aquafeed which by its nature is used only a commercial context.

Additional labelling requirements are set out in Annex II (article 11(4)), while permitted tolerances for discrepancies between the labelled compositional values of feed materials or compound feeds and the values analysed in official controls are listed in Annex IV.

Subsequent provisions:

- address responsibility for feed labelling (article 12).
- require claims for feed to be objective and verifiable and justifiable (article 13).
- require the prominent placing of mandatory labelling particulars in a conspicuous, clearly legible and indelible manner, in the official language or at least one of the official languages of the Member State or region in which it is placed on the market (article 14).
- set out detailed mandatory labelling requirements in terms of the type of feed, the name of the feed business operator, establishment approval number if relevant, the batch of lot reference number (with terms ‘batch’ or ‘lot’ defined in article 3 to mean “an identifiable quantity of feed determined to have common characteristics, such as origin, variety, type of packaging, packer, consignor or labelling, and, in the case of a production process, a unit of production from a single plant using uniform production parameters or a number of such units, when produced in continuous order and stored together), net quantity, list of additives and moisture content (article 15);
- impose specific mandatory labelling requirements for feed materials in terms of the name used in the feed catalogue and a compulsory declaration regarding the category of feed as well as specific requirements where additives are used (article 16).
- specific mandatory labelling requirements for compound feed (article 17).
- include provisions that are not relevant to aquafeed relating to labelling requirements for feed intended to for particular nutritional purposes and petfood (articles 18 and 19).
- set out additional mandatory labelling requirements for non-compliant feed (article 20).
- provide for derogations in certain specific circumstances (article 21); and
- address voluntary labelling (article 22) and packaging (article 23).

Article 24(1) provides for the establishment the Community Catalogue of feed materials (hereinafter ‘the Catalogue’) as a tool to improve the labelling of feed materials and compound feed, to facilitate the exchange of information on the properties of products and to list feed materials in a non-exhaustive manner.

The Catalogue must contain the following minimum particulars in respect of each listed feed material: (a) the name; (b) the identification number; (c) a description of the feed material including information on the manufacturing process, if appropriate; (d) particulars replacing the compulsory declaration for the purpose of Article 16(1)(b); and (e) a glossary with the definition of the different processes and technical expressions mentioned.

Article 24(2) required the adoption of first version of the Catalogue by March 2010 at the latest and provision is made its periodic review and amendment in article 24(3) which is expressed to apply without the prejudice to the to the safety requirements laid down in Article 4 of the regulation (article 24(4)). Article 24(5) provides that while the use of the Catalogue by feed business operators is voluntary, the name of a feed material listed in the Catalogue may be used only on condition that all relevant provisions of the Catalogue are complied with.

In cases where a feed material that is not listed in the Catalogue is first placed on the market, the person so doing must immediately notify its use to the representatives of the European feed business sectors referred to in article 26(1), who must in turn publish a register of such notifications on the Internet and update the register on a regular basis. The register itself is available at https://www.feedmaterialsregister.eu/register.

Article 25(1) requires the EC to encourage the development of two Community Codes of good labelling practice (“the Codes”), one for pet food and one for compound feed for food producing animals, which may include a section concerning compound feed for fur animals. The aim of the Codes is to improve the appropriateness of labelling, and they must, in particular, include provisions on the presentation of labelling particulars provided for in article 14, on the voluntary labelling provided for in article 22 and on the use of claims provided for in article 13 of the regulation.

Again, while the use of the Codes by the feed business operators is voluntary, use of any of the Codes may be indicated on the labelling only on condition that all relevant provisions of such Code are complied with.

Article 26(1) provides that draft amendments to the Catalogue as well as drafts of the Codes and any amendments to them must be developed and amended by all appropriate representatives of “European feed business sectors” in consultation with other concerned parties, such as feed users and in collaboration with the competent authorities of the Member States and, where appropriate, EFSA. In addition, relevant experience from opinions issued by EFSA and scientific or technological developments is to be taken into account.

Detailed procedures for the amendment of the Catalogue are then set out in the remainder of article 26.

Finally, mention can be made of the non-binding guidelines adopted by the EC in 2011 on the distinction between feed materials, feed additives, biocidal products and veterinary medicinal products.[142] After noting, among other matters, that a product cannot be a feed material and a feed additive at the same time, the guidelines set out three criteria to be simultaneously considered in a case by case evaluation, namely production and processing method, safety and mode of use and functionality ([143]).

8.2.1.9. Regulation No. 1069/2009, the Animal By-products Regulation

Regulation No. 1069/2009, the Animal By-products Regulation ([144]) sets out public health and animal health rules for animal by-products and derived products, in order to prevent and minimise risks to public and animal health arising from those products, and in particular to protect the safety of the food and feed chain.

The scope of the regulation is set out in its article 2. It applies to: (a) animal by-products and derived products which are excluded from human consumption under Community legislation; and (b) products which pursuant to a decision by an operator are destined for purposes other than human consumption in the form of: (i) products of animal origin which may be destined for human consumption under Community legislation; (ii) raw materials for the production of products of animal origin.

Article 3 sets out a number of definitions including that of “aquatic animal” which is defined by reference to the definition in the now repealed Council Directive 2006/88/EC of 24 October 2006 on animal health requirements for aquaculture

([142]) 2011/25/EU: Commission Recommendation of 14 January 2011 establishing guidelines for the distinction between feed materials, feed additives, biocidal products and veterinary medicinal products Text with EEA relevance (OJ L 11, 15.1.2011, p. 75).

([143]) For a critique of these guidelines, see Klaus. B. “Distinction between Feed Materials and Feed Additives in Consideration of the General Principles of Law: with a View to the Demarcation Guidelines established by the European Commission with Recommendation No 2011/25/EU of 14 January 2011” *European Food and Feed Law Review*, 2011, Vol. 6, No. 1 (2011), pp. 2-15

([144]) Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (OJ L 300, 14.11.2009, p. 1).

animals and products thereof, and on the prevention and control of certain diseases in aquatic animals ([145]) replaced the Animal Health Law which is described in more detail below.

Other key definitions include “animal by-products”, which are defined to mean “entire bodies or parts of animals, products of animal origin or other products obtained from animals, which are not intended for human consumption, including oocytes, embryos and semen” and “derived products”, which are defined to mean “products obtained from one or more treatments, transformations or steps of processing of animal by-products”.

The basic obligations of operators (defined in article 3 to mean “natural or legal persons having an animal by-product or derived product under their actual control, including carriers, traders and users) are set out in Section 2 by reference to the “starting point” and the “end point” in the manufacturing chain. The starting point arises, in accordance with article 4(1), as soon as operators generate animal by-products or derived products falling within the scope of the regulation, at which point they must identify them and ensure that they are dealt with in accordance its provisions.

To this end, operators must ensure at all stages of collection, transport, handling, treatment, transformation, processing, storage, placing on the market, distribution, use and disposal within the businesses under their control that animal by-products and derived products satisfy the requirements of the regulation that are relevant to their activities article (4(2)).

The Member States are in turn required to monitor and verify compliance by operators with the requirements of the regulation along the entire chain of animal by-products and derived products (article 4(3)) and to that end they must maintain a system of “official controls” in accordance with relevant EU legislation. The Member States must also ensure that an adequate system is in place on their territory to ensure that animal by-products are: (a) collected, identified and transported without undue delay; and (b) treated, used or disposed of in accordance with the regulation, either singly or jointly with other Member States (articles 4(4) and (5)).

The end point in the manufacturing chain is a little more complex. Article 5(1) first addresses the end point for derived products listed in article 33 of the regulation which are not relevant to aquafeed. It next considers the “end point” for derived products listed in articles 32, 35 and 36 that no longer pose a risk to human health or any significant risk to public or animal health, beyond which they are no longer subject to the requirements of the regulation at which point the may be placed on the market and are no longer be subject to official

([145]) OJ L 328, 24.11.2006, p. 14

controls. Under these headings, only article 36 is relevant to aquafeed and the implications will be considered further below.

Article 6 provides that animal by-products and derived products from susceptible species must not be dispatched from holdings, establishments, plants or zones that are subject to restrictions in accordance with EU veterinary legislation or due to the presence of specified serious transmissible diseases.

In accordance with article 7(1), animal by-products must be categorised into specific categories that reflect the level of risk to public and animal health posed by those products in accordance with the lists set out in articles 8-10 of the regulation, with derived products generally being subject to the rules for the category of animal by-products from which they have been derived.

Article 8 lists Category 1 material which, includes infected animals and animal by-products and is the highest risk category. In accordance with article 12 of the regulation, such material must essentially be safely disposed of.

Category 2 material, intermediate risk material, is listed in article 9 and includes manure, non-mineralised guano and digestive tract content, animal by-products containing residues of authorised substances or contaminants exceeding the permitted levels, products of animal origin deemed unfit for human consumption, animals and parts of animals that died otherwise than by being slaughtered. Such material must either be disposed of or alternatively it may be used for non-feed purposes such as the manufacture of organic fertilizers or transformation into biogas or in certain circumstances used for the manufacture and placing on the market of certain specified products that are not feed products.

Category 3, material which has the lowest risk category, is listed in article 10 and includes carcases and parts of slaughtered or killed animals that are fit for human consumption in accordance with EU legislation, but are not so used for commercial reasons, as well as various body parts such as heads of poultry, pig bristles, other poultry by-products, blood as well as aquatic animals, and parts of such animals, except sea mammals, which did not show any signs of disease communicable to humans or animals and animal by-products from aquatic animals originating from establishments or plants manufacturing products for human consumption. Category 3 material may, in accordance with article 14 be disposed of or used for, among other matters, processing for the manufacturing of feed for farmed animals other than fur animals and, thereafter, being placed on the market.

Certain uses of animal by-products, and derived products, are prohibited in accordance with article 11 and these include, “the feeding of farmed fish with processed animal protein derived from the bodies or parts of bodies of farmed fish of the same species”, to minimise the risk of spreading diseases through aquafeed as averted to in the WOAH Aquatic Animal Health Code.

Article 15 provides for the adoption by the EC of a range of implementing measures including as regards the use of certain animal by-products for feeding to farmed animals. Subsequent articles address issues that are not directly relevant to aquafeed including the possibility of certain derogations (article 16), research and other specific purposes (article 17), special feeding purposes (article 18).

Title II of the regulation sets out a number of general obligations relating to the collection, transport and traceability of animal by-products (articles 21 and 22), the registration and approval of operators, establishments and plants (article 22) including a requirement for approval of plants by the competent authority (article 23), general hygiene requirements (article 24), compliance monitoring by operators (article 25), the introduction and application of HACCP (article 29) and the development of national guides for good practice for the application of HACCP (article 30).

Chapter II of Title II is concerned with “Placing on the market”. While most of its content is not relevant to aquafeed, article 31 is. It provides that “animal by-products and derived products destined for feeding to farmed animals, excluding fur animals, may only be placed on the market provided: (a) they are or they are derived from Category 3 material (with certain limited exceptions; (b) they have been collected or processed, as applicable, in accordance with the conditions for pressure sterilisation or other conditions to prevent risks arising to public and animal health in accordance with measures set out in subordinate legislation; and (c) they come from approved or registered establishments or plants, as applicable for the animal by-product or derived product concerned.

The import into the EU (and sending in transit through the EU) of animal by-products and derived products is addressed in article 41 which provides the relevant requirements of the regulation and related subordinate legislation must be at least as stringent as those applicable in the EU including as regards production and marketing. Moreover, as regards category 3 material and products derived therefrom (in other words material products that may be used in aquafeed), must be come from a third country included in a list of approved third countries drawn up by the EC, must come from establishments or plants approved or registered by the competent authority of the third country of origin and listed by that authority for that purpose; and must be accompanied at the point of entry into the EI where the veterinary checks take place by documentation such as a commercial document or a health certificate and where appropriate by a declaration, which corresponds to a model set out in subordinate legislation adopted by the EC. Additional requirements for the inclusion of a third country in the approved list are also specified.

Finally, Title III of the regulation addresses official controls and final provisions.

Detailed provisions for the implementation of the Animal By-products Regulation were subsequently set out in subordinate legislation ([146]).

8.2.1.10. Commission Regulation No. 68/2013, the Catalogue of Feed Materials

The Catalogue of Feed Materials required by the Animal Feed Regulation, is contained as an Annex to Commission Regulation No. 68/2013, the Catalogue of Feed Materials, as amended ([147]).

The catalogue is set out in three parts as follows:

- Part A, General provisions, which contains the explanatory background to the Catalogue.
- Part B, Glossary of processes; and
- Part C, which contains the list of feed materials which are set out in 13 categories as follows:
  1. Cereal grains and products derived thereof
  2. Oil seeds, oil fruits, and products derived thereof
  3. Legume seeds and products derived thereof
  4. Tubers, roots, and products derived thereof
  5. Other seeds and fruits, and products derived thereof
  6. Forages and roughage, and products derived thereof
  7. Other plants, algae, fungi and products derived thereof
  8. Milk products and products derived thereof
  9. Land animal products and products derived thereof
  10. Fish, other aquatic animals and products derived thereof
  11. Minerals and products derived thereof
  12. Products and co-products obtained by fermentation using microorganisms
  13. Miscellaneous

([146]) Commission Regulation (EU) No 142/2011 of 25 February 2011 implementing Regulation (EC) No 1069/2009 of the European Parliament and of the Council laying down health rules as regards animal by-products and derived products not intended for human consumption and implementing Council Directive 97/78/EC as regards certain samples and items exempt from veterinary checks at the border under that Directive (OJ L 54, 26.2.2011, p. 1) and Commission Delegated Regulation (EU) 2023/1605 of 22 May 2023 supplementing Regulation (EC) No 1069/2009 of the European Parliament and of the Council as regards the determination of end points in the manufacturing chain of certain organic fertilisers and soil improvers (OJ L 198, 8.8.2023, p. 1).

([147]) Commission Regulation (EU) No 68/2013 of 16 January 2013 on the Catalogue of feed materials (OJ L 29, 30.1.2013, p. 1).

8.2.1.11. Regulation No. 1143/2014, the Invasive Alien Species Regulation

Regulation No. 1143/2014, the Invasive Alien Species Regulation ([148]), sets out rules to prevent, minimise and mitigate the adverse impact on biodiversity of the introduction and spread within the EU, both intentional and unintentional, of invasive alien species (article 1). The potential relevance of this regulation to the topic of aquafeed arises in connection with the import and use of non-endemic insect species for use as aquafeed material.

The term “invasive alien species” is defined to mean “an alien species whose introduction or spread has been found to threaten or adversely impact upon biodiversity and related ecosystem services” while the word “introduction” is defined in rather broad terms to mean “the movement, as a consequence of human intervention, of a species outside its natural range”.

Article 4 of the regulation requires the adoption of a list of “invasive alien species of Union concern” that must be renewed at six-year intervals, while article 5 makes provision for a risk assessment in relation to the current and potential range of invasive alien species. The list was first adopted in the form of subordinate legislation in 2016 and has since been updated on three occasions ([149]).

Article 7 provides, in short, that invasive alien species of Union concern must not be intentionally brought into the territory EU, kept, bread or placed on the market. While the possible of a derogation through the establishment by the Member States of a permit system, this is limited to the purposes of research or *ex-situ* conservation.

Additionally, Member States may establish their own national lists of invasive alien species of Member State concern and apply the same restrictions.

([148]) Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species (OJ L 317, 4.11.2014, p. 35).

([149]) Commission Implementing Regulation (EU) 2016/1141 of 13 July 2016 adopting a list of invasive alien species of Union concern pursuant to Regulation (EU) No 1143/2014 of the European Parliament and of the Council (OJ L 189, 14.7.2016, p. 4).

8.2.1.12. Regulation No. 2016/429, the Animal Health Law

The overall aim of Regulation No. 2016/429, the Animal Health Law ([150]), is to implement the commitments and visions provided for in the Animal Health Strategy 2007, including the ‘One health’ principle, and to consolidate the legal framework for a common Union animal health policy through a single, simplified and flexible regulatory framework for animal health Animal Health Strategy for the European Union in line with the EU’s commitments under international law. It is also the mechanism whereby the EU and Member States implement the WOAH Aquatic Animal Health Code.

This is done by setting out rules for the prevention and control of animal diseases which are transmissible to animals or to humans on a range of issues including: the prioritisation and categorisation of diseases of EU concern and the establishment of responsibilities for animal health; the early detection, notification and reporting of diseases, surveillance, eradication programmes and disease–free status; disease awareness, preparedness and control; the registration and approval of establishments and transporters, movements and traceability of animals, germinal products and products of animal origin within the EU; the entry of animals, germinal products, and products of animal origin into the EU and the export of such consignments from the EU; emergency measures to be taken in in the event of a disease emergency situation (article 1).

In other words, the Animal Health Law has a broad scope, one that extends far beyond aquafeed. Nevertheless, it is relevant to aquafeed in terms of the potential relationship between contaminated fed and (aquatic) animal health. Indeed, the relationship between animal health and food and feed safety is one of the factors that must be taken into account by the rules adopted pursuant to article 1 (article 2).

Among the terms defined in article 4, are “animal by–products”, defined to mean “entire bodies or parts of animals, products of animal origin or other products obtained from animals, which are not intended for human consumption, excluding germinal products”, “derived products”, defined to mean “products obtained from one or more treatments, transformations or steps in the processing of animal by–products, as well as a general definition of “products” to mean (a) germinal products; (b) products of animal origin; (c) animal by–products and derived products.

In terms of its scope, the regulation applies to products of animal origin, animal by–products and derived products, without prejudice to the rules laid down in

([150]) Regulation (EU) 2016/429 of the European Parliament and of the Council of 9 March 2016 on transmissible animal diseases and amending and repealing certain acts in the area of animal health (‘Animal Health Law’) (OJ L 84, 31.3.2016, p. 1).

the Animal By-products Regulation and “facilities, means of transport, equipment and all other paths of infection and material involved or potentially involved in the spread of transmissible animal diseases” (article 2). In particular, Title II of Part IV of the regulation applies to (a) aquatic animals, and animals which are not aquatic animals, but which may transmit diseases affecting aquatic animals; (b) products of animal origin from aquatic animals.

The main practical relationship with the regulation and aquafeed arises in terms of aquatic animal disease control measures which may include placing any establishment, food and feed business or animal by–products establishment concerned where a relevant disease is suspected of having occurred under official surveillance and therefore taking appropriate response measures including the preparation of an inventory of products/animal by-products, implementing disease control measures and undertaking an enquiry (article 55).

In addition, article 222 provides that every “operator”, defined in this regulation to mean “any natural or legal person having animals or products under his responsibility, including for a limited duration of time, but excluding pet keepers and veterinarians”, must take appropriate preventive measures to ensure that, during all stages of the production, processing and distribution of products of animal origin from aquatic animals, other than live aquatic animals, those products do not cause the spread of listed or emerging diseases and that they do not source such products from establishments or food businesses that are subject to animal health related restrictions. Regulation No. 2016/2031, the Plant Protection Regulation ([151]), implements the obligations of the EU and Member States relating to the IPPC described in section 2.1.3 above. Its relevance as regards aquafeed concerns the need for imports of plant products, including grains and seeds used to manufacture aquafeeds, to be accompanied by a phyto-sanitary certificate in the prescribed form. Detailed provisions for the application of this regulation are set out in subordinate legislation ([152]).

([151]) Regulation (EU) 2016/2031 of the European Parliament of the Council of 26 October 2016 on protective measures against pests of plants, amending Regulations (EU) No 228/2013, (EU) No 652/2014 and (EU) No 1143/2014 of the European Parliament and of the Council and repealing Council Directives 69/464/EEC, 74/647/EEC, 93/85/EEC, 98/57/EC, 2000/29/EC, 2006/91/EC and 2007/33/EC OJ L 317, 23.11.2016, p. 4

([152]) Commission Implementing Regulation (EU) 2019/2072 of 28 November 2019 establishing uniform conditions for the implementation of Regulation (EU) 2016/2031 of the European Parliament and the Council, as regards protective measures against pests of plants, and repealing Commission Regulation (EC) No 690/2008 and amending Commission Implementing Regulation (EU) 2018/2019 (OJ L 319, 10.12.2019, p. 1).

8.2.1.13. Regulation No. 2017/625, the Official Controls Regulation

Regulation No. 2017/625, the Official Controls Regulation ([153]), lays down rules for the performance of official controls and other official activities by the competent authorities of the Member States to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection products, in other words many if not all of the instruments that are relevant to aquafeed.

The regulation is set out in eight titles as follows: Title I - Subject Matter, Scope and Definitions; Title II - Official Controls and Other Official Activities in Member States; Title III - Reference Laboratories and Reference Centres; Title IV - Administrative Assistance and Cooperation; Title V – Planning and Reporting; Title VI – Union Activities; Title VII – Enforcement Action; and Title VIII - Common Provisions.

8.2.1.14. Commission Regulation No. 2017/893, the Processed Animal Protein Regulation

Commission Regulation No. 2017/893, the Processed Animal Protein Regulation ([154]), is particularly relevant as regards the use of insects in aquafeed.

In outline this Commission Regulation amends four annexes of Regulation No. 999/2001, the Transmissible Spongiform Encephalopathies Regulation ([155]) to allow the use of various animal products in feed including aquafeed. The latter regulation, which was adopted following the detection of bovine spongiform encephalitis so-called “mad-cow disease”, as a result of the use of animal by-products from diseased animals in animal feed.

The Processed Animal Protein Regulation authorises the feeding of the following seven insect species to aquaculture animals: the black soldier fly (*H. illucens*), the common housefly (*Musca domestica*), the yellow mealworm (*T.*

([153]) Regulation (EU) 2017/625 of the European Parliament and of the Council of 15 March 2017 on official controls and other official activities performed to ensure the application of food and feed law, rules on animal health and welfare, plant health and plant protection

([154]) Commission Regulation (EU) 2017/893 of 24 May 2017 amending Annexes I and IV to Regulation (EC) No 999/2001 of the European Parliament and of the Council and Annexes X, XIV and XV to Commission Regulation (EU) No 142/2011 as regards the provisions on processed animal protein (OJ L 138, 25.5.2017, p. 92).

([155]) Regulation (EC) No 999/2001 of the European Parliament and of the Council of 22 May 2001 laying down rules for the prevention, control and eradication of certain transmissible spongiform encephalopathies (OJ L 147, 31.5.2001, p. 1)

molitor), the lesser mealworm (*A. diaperinus*), the house cricket (*A. domesticus*), the banded cricket (*G. sigillatus*) and the field cricket (*Gryllus assimilis*).

In addition, the use of silkworm (*Bombyx mori*) as authorised through subordinate legislation in 2021 ([156]).

8.2.1.15. Regulation No. 2018/848, the Organic Production and Labelling Regulation

The objective of Regulation No. 2018/848, the Organic Production and Labelling Regulation ([157]), is to establish the principles of organic production and to lay down the rules concerning organic production, related certification and the use of indications referring to organic production in labelling and advertising. ‘Organic production’ is defined in article 2 to mean the use of production methods that comply with the regulation at all stages of production, preparation and distribution, including the “conversion period” which is explained in article 10. The regulation also sets out a number of controls additional to those laid down in the Official Controls Regulation (article 1).

In terms of its scope, the regulation applies to the products originating from agriculture, including aquaculture and beekeeping, listed in Annex I to the TFEU in the form of: (a) live or unprocessed agricultural products, including seeds and other plant reproductive material; (b) processed agricultural products for use as food; and (c) feed.

It also applies to products originating from those products, where such products are, or are intended to be, produced, prepared, labelled, distributed, placed on the market, imported into or exported from the Union, as well as to products listed in Annex I to the regulation (which are not relevant to aquafeed). The regulation applies to any operator involved, at any stage of production, preparation and distribution, in activities relating organic products.

An extensive list of definitions is set out in article 3, including one for “organic product”, defined as “a product resulting from organic production, other than a product produced during the conversion period referred to in Article 10” but excluding the products of hunting or fishing of wild animals. “Aquaculture” and

([156]) Commission Regulation (EU) 2021/1925 of 5 November 2021 amending certain Annexes to Regulation (EU) No 142/2011 as regards the requirements for placing on the market of certain insect products and the adaptation of a containment method (OJ L 393, 8.11.2021, p. 4).

([157]) Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products and repealing Council Regulation (EC) No 834/2007 (OJ L 150, 14.6.2018, p. 1).

“aquaculture products” are defined by reference to the definition contained in the CFP Basic Regulation (described below).

The general objectives for organic production are set out in article 4. These are essentially what can be described as “environmental” objectives, such as contributing to the protection of the environment and the climate, maintaining soil fertility, contributing to a high level of biodiversity but also include “contributing to high animal welfare standards and, in particular, to meeting the species-specific behavioural needs of animals”.

Article 5 provides that organic production is a sustainable management system that is based on a number of general principles that it lists and which include the production of “a wide variety of high-quality food and other agricultural and aquaculture products that respond to consumers’ demand for goods that are produced by the use of processes that do not harm the environment, human health, plant health or animal health and welfare”, “ensuring the integrity of organic production at all stages of the production, preparation and distribution of food and feed” and restricting the use of “external inputs” except in cases where external inputs are required in which case they are limited to *inter alia* inputs from organic production and natural or naturally-derived substances.

A number of specific principles applicable to agricultural activities and aquaculture are set out in article 6 including the principle that aquatic organisms should be with feed from sustainably exploited fisheries in accordance with CFP Basic Regulation or with “organic feed composed of agricultural materials resulting from organic production, including organic aquaculture, and of natural non-agricultural substances”.

While article 7 is not relevant to aquafeed, article 8, which sets out “Specific principles applicable to the processing of organic feed” clearly is (and the regulation uses the General Food Law definition of “feed”). Article 7 provides that “the production of processed organic feed shall be based, in particular, on the following specific principles: (a) the production of organic feed from organic feed materials; (b) the restriction of the use of feed additives and processing aids, so that they are used to a minimum extent and only in cases of essential technological or zootechnical needs or for particular nutritional purposes; (c) the exclusion of substances and processing methods that might be misleading as regards the true nature of the product; (d) the processing of organic feed with care, preferably through the use of biological, mechanical and physical methods”.

Article 10 is concerned with “conversion”, meaning the transition from non-organic to organic production. Farmers and operators that produce algae or aquaculture animals must comply with a “conversion period”, which starts after the farmer or operator notifies the competent authorities that the activity is subject to the control system for organic production.

Article 11 GMOs prohibits the use of products produced from GMOs, and products produced by GMOs in organic feed, while article 12 requires compliance with plant protection rules contained in Part I of Annex II of the regulation. Among a range of specific rules that are not relevant to aquafeed contained in subsequent articles, mention can be made of article 15, which sets outs production rules for algae and aquaculture animals in accordance with Part III of Annex III.

Part III sets out several rules about the feed to be used in organic aquaculture production. In particular:

- the “plant fraction of feed for fish, crustaceans and echinoderms must be organic and the feed fraction derived from aquatic animals shall originate from organic aquaculture or from fisheries that have been certified as sustainable under a scheme recognised by the competent authority in line with the principles set out in the CFP Basic Regulation.
- non-organic feed materials of plant, animal, algal or yeast origin, feed materials of mineral or microbial origin, feed additives, and processing aids can only be used if they have been authorised under the Organic Production Regulation for use in organic production.
- growth promoters and synthetic amino acids must not be used (paragraph 3.1.3.1).

Feed for carnivorous aquaculture animals must be sourced with the following priorities:

a) organic feed of aquaculture origin.
b) fish meal and fish oil from organic aquaculture trimmings sourced from fish, crustaceans or molluscs.
c) fish meal and fish oil and feed material of fish origin derived from trimmings of fish, crustaceans or molluscs already caught for human consumption in sustainable fisheries.
d) fish meal and fish oil and feed material of fish origin derived from whole fish, crustaceans or molluscs caught in sustainable fisheries and not used for human consumption.
e) organic feed materials of plant or animal origin (article 3.1.3.3).

In addition, an operator (defined in article 3 as a natural or legal person responsible for ensuring compliance with the regulation at every stage of production, preparation and distribution under that person’s control) must comply with:

- specific rules for feed for fish in inland waters, penaeid shrimps and freshwater prawns and tropical freshwater fish during the grow-out phase and as regards the use of organic cholesterol during the grow-out phase and

in earlier life stages in nurseries and hatcheries, of penaeid shrimps and freshwater prawns (*Macrobrachium spp.*) (paragraph 3.1.3.4).

- additional rules on organic aquafeed adopted by the Commission on the basis of subordinate legislation.

Article 17 of the regulation sets out general production rules for processed feed and requires operators producing processed feed, including aquafeed, to comply with detailed production rules set out in Part V of Annex II. Curiously, neither “processed” nor “processed feed” are defined in article 3. The word “processing” is defined by reference to point (m) of Article 2 (1) of Regulation (EC) No 852/2004 to mean “any action that substantially alters the initial product, including heating, smoking, curing, maturing, drying, marinating, extraction, extrusion or a combination of those processes”.

Article 23 requires operators to ensure that organic products and in-conversion products are collected, packaged, transported and stored in accordance with the rules set out in Annex III of the regulation while article 24 empowers the EC to authorise certain products and substances for use in organic production while subsequent articles address aspects of compliance.

Detailed provisions on the labelling of organic products, including aquafeed, are set out in Chapter IV of the regulation, while the issue of certification is addressed in Chapter V. Prior to placing any products on the market as ‘organic’ or as ‘in-conversion’ an operator must notify the competent authorities of the relevant Member State.

Article 35 provides for the issuance of a certificate by Competent authorities, or, where appropriate, control authorities or control bodies.

8.2.2. Environmental legislation

8.2.2.1. Regulation (EU) 2023/1115, the Deforestation Free Product Regulation

Regulation (EU) 2023/1115, the Deforestation Free Product Regulation ([158]), regulates the placing and making available on the EU market as well as the export from the EU of products listed in Annex I that contain, have been fed with

([158]) Regulation (EU) 2023/1115 of the European Parliament and of the Council of 31 May 2023 on the making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010 (OJ L 150, 9.6.2023, p. 2060)

or have been made using relevant commodities, namely cattle, cocoa, coffee, oil palm, rubber, soya and wood.

It is relevant to the aquafeed sector because among the products listed in Annex I are soya beans and other soya products including oil and flour, and palm oil both of which are used in aquafeed.

The objective of the regulation is to: (a) minimise the EU’s contribution to deforestation and forest degradation worldwide, thereby contributing to a reduction in global deforestation; and (b) reduce the EU’s contribution to greenhouse gas emissions and global biodiversity loss (article 1).

In outline, “relevant commodities” (namely cattle, cocoa, coffee, oil palm, rubber, soya and wood) and relevant products (as described in Anne I) must not be placed or made available on the EU market or exported from the EU, unless they:

a) are “deforestation-free”, meaning that they that have been made using, relevant commodities that were produced on land that has not been subject to “deforestation”, meaning the conversion of forest to agricultural use, whether human-induced or not after 31 December, 2020.
b) have been produced in accordance with the relevant legislation of the country of production; and
c) they are covered by a due diligence statement (article 3).

Subsequent provisions in Chapter 2 set out:

- the obligations of “operators” (natural or legal persons who place relevant products on the market or exports them as part of a commercial activity), which include a due diligence obligation under article 8 as well as the duty not to place products on the market without a due diligence statement with less onerous rules for small and medium enterprises (SMEs) (article 4).
- the obligations of traders, (persons other than operators who make products available on the market), again with less onerous rules for SMEs (article 5).
- provision for the mandating of authorised representatives to submit the due diligence statement on their behalf (article 6).
- the basic due diligence obligation in terms of information, risk assessment and risk mitigation (article 8).
- information requirements (article 9).
- risk assessment (article 10).
- risk mitigation (article 11).
- the establishment and maintenance of due diligence systems by operators, reporting and record keeping (article 12); and
- a simplified due diligence that applies in certain circumstances (article 13).

Chapter 3 sets out the obligations of the Member States and their competent authorities including oversight requirements to ensure compliance with the regulation, while Chapter 4 sets out relatively detailed procedures for relevant products entering or leaving the EU market.

A country benchmarking system and provisions on cooperation with third countries (i.e. non-EU countries) is the subject matter of Chapter 5, while Chapter 6 creates a mechanism for natural or legal persons to submit their substantiated concerns, (defined to mean means “a duly reasoned claim based on objective and verifiable information regarding non-compliance” with the regulation) to the competent authorities when they consider that one or more operators or traders are not complying with the regulation. The implementation of the regulation is to be supported through the establishment by the EC of a specific information system. Chapter 8 provided for the evaluation of the regulation while final provisions are contained in Chapter 9.

8.2.1. Fisheries Legislation

8.2.1.1. Regulation No. 1380/2013, the CFP Basic Regulation

The overall objective of Regulation No. 1380/2013, the CFP Basic Regulation ([159]), is to ensure that “fishing and aquaculture activities are environmentally sustainable in the long-term and are managed in a way that is consistent with the objectives of achieving economic, social and employment benefits, and of contributing to the availability of food supplies” (article 2(1)).

Unlike most of the other legislation considered in this study, the CFP Basic Regulation contains a definition of “aquaculture” (“the rearing or cultivation of aquatic organisms using techniques designed to increase the production of the organisms in question beyond the natural capacity of the environment, where the organisms remain the property of a natural or legal person throughout the rearing and culture stage, up to and including harvesting”). Moreover, in its Part VI on aquaculture, the CFP Basic Regulation, requires the Member States to establish a multiannual national strategic plans for the development of aquaculture activities on their territories that must include among their aims, “the promotion of aquaculture practices and research with a view to enhancing positive effects on the environment and on the fish resources, and to reducing

([159]) Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC (*OJ L 354, 28.12.2013, p. 22).*

negative impacts, including reducing pressure on fish stocks used for feed production, and increasing resource efficiency”.

Both generally and as regards aquaculture, is to promote the issues of sustainability and in terms of aquafeed, this issue arises primarily in terms of the sustainable use of fish and fish products in aquafeed production. In this regard, the CFP Basic Regulation also includes among its objectives the progressive restoration and thereafter the maintenance of fish stocks above biomass levels capable of producing maximum sustainable yield.

To this end, the CFP sets out a range of management measures including the establishment of annual fishing opportunities for different fish stocks and the allocation of such opportunities among the Member States for different fish species ([160]). These include a number of fish species used for fish oil or fish meal.

8.2.1.2. Regulation No. 1005/2008, the IUU Regulation

As regards the sustainability of fish and fishery products used in aquafeed that are sourced from outside the EU, Regulation No. 1005/2008, the IUU Regulation ([161]) addresses the issue of illegal, unreported and unregulated (IUU) fishing, or put another way, deliberately irresponsible fishing.

Among other matters, article 12 of the regulation prohibits the import into the EU of fishery products obtained from IUU fishing. To this end, fishery products may only be imported into the EU when accompanied by a catch certificate validated by the flag State of the fishing vessel or fishing vessels which made the catches from which the fishery products have been obtained. Such a certificate must be in the format set out in annex II to the regulation and must certify that such catches have been made in accordance with applicable laws, regulations and international conservation and management measures.

However, particularly as regards fishing in waters under coastal jurisdiction, to be effective such a system requires the coastal state concerned to adopt, implement and enforce appropriate conservation and management measures in line with the FAO Code of Conduct for Sustainable Fisheries, described above.

([160]) Council Regulation (EU) 2025/202 of 30 January 202 fixing for 2025 and 2026 the fishing opportunities for certain fish stocks, applicable in Union waters and, for Union fishing vessels, in certain non-Union waters, and amending Regulation (EU) 2024/257 as regards fishing opportunities for 2025 (OJ L 204, 31.1.2025, p. 1).

([161]) Council Regulation (EC) No 1005/2008 of 29 September 2008 establishing a community system to prevent, deter and eliminate illegal, unreported and unregulated fishing, amending Regulations (EEC) No 2847/93, (EC) No 1936/2001 and (EC) No 601/2004 and repealing Regulations (EC) No 1093/94 and (EC) No 1447/1999 (OJ L 286, 29.10.2008, p. 1).

In the case of some developing countries this may not always be the case. In its resolution of 4 October 2022, “Striving for a sustainable and competitive EU aquaculture: the way forward”, the European Parliament noted a large proportion of fishmeal and fish oil is caught in the exclusive economic zones of developing countries and expressed particular concern about the unsustainable production of a growing number of Chinese-managed fishmeal and fish oil factories in West Africa.

8.3. Rules and regulation in Norway & UK

8.3.1. Norway

Norway, as a member of the European Free Trade Association (EFTA), is also a party to the Agreement on the European Economic Area (the EEA Agreement) that concluded between the EFTA members (which also include Iceland and Liechtenstein) and the members of the EU.

The aim of the EEA Agreement, which entered into force on 1 January 1994, is to “promote a continuous and balanced strengthening of trade and economic relations between the Contracting Parties with equal conditions of competition, and the respect of the same rules, with a view to creating a homogeneous European Economic Area, hereinafter referred to as the EEA” (Article 1(1)).

In other words, the EEA groups together the EU Member States and EFTA members into a single market subject to the same rules. These rules cover the “four freedoms” (the free movement of goods, capital, services and persons), competition and state aid, and closer cooperation in other fields, such as research and development, the environment, education and social policy. The rules also guarantee equal rights and obligations within the single market for citizens and businesses throughout the EEA.

However, certain areas of EU policy are not covered by the EEA Agreement including the customs union, the Common Trade Policy and the Common Agriculture and Fisheries Policies (although the EEA Agreement contains provisions on various aspects of trade in agricultural and fish products).

The law-making procedure is also different as the EFTA members have not transferred any legislative competences to the EEA institutions. Consequently, all decisions are therefore taken by the EFTA members on the basis of unanimity. Whenever an EEA-relevant legal act is amended or a new one adopted by the EU, a corresponding amendment is made to the relevant Annex of the EEA Agreement.

In accordance with article 7 the EEA Agreement, an act corresponding to an EU regulation becomes part of the internal legal order of an EFTA member in the same manner that a regulation is binding in its entirety and directly applicable in an EU Member State in accordance with article 288 TFEU. However, just as the TFEU leaves it up the national authorities of each Member State the choice of form and methods for the transposition of a directive, notwithstanding that the result to be achieved is binding, as regards an act corresponding to an EU directive, the EEA Agreement leaves to the authorities of the Contracting Parties the choice of form and method of implementation.

As seen above, the vast majority of the legal instruments of the EU policy and legal framework for aquafeed are in the form of regulations. Those regulations that relate to food and feed law are automatically part of Norway’s legal order, with specifically Norwegian legislation only necessary to enable the implementation of those regulations by identifying the relevant competent authority and to set out sanctions for non-compliance, just as is required by EU Member States.

The only exception to this principle as regards food and feed law, concerns Directive No. 2002/32/EC, the Undesirable Substances in Animal Feed Directive, which was required to be transposed into Norwegian law. However, curiously the EFTA Surveillance Authority has no information about the implementation of this directive by Norway on its database ([162]).

While media reports suggest that the Norwegian Government is proposing that 25% of aquaculture food should be national sourced, this has yet to be legislated for.

8.3.2. United Kingdom

While the UK was a member of the EU, the EU regulations relating to the aquafeed sector applied there just as in the current EU Member States.

The transposition of Directive No. 2002/32/EC, the Undesirable Substances in Animal Feed Directive, took place on the basis of the Feeding Stuffs, the Feeding Stuffs (Sampling and Analysis) and the Feeding Stuffs (Enforcement) (Amendment) (England) Regulations 2003 (and equivalent regulations for Scotland, Northern Island and Wales) which were adopted pursuant to the Agriculture Act 1970, the withdrawal of the UK from the EU has had no impact on these regulations which remain in force.

([162]) See https://www.eftasurv.int/internal-market/implementing-eea-law-national-law/implementation-status-database?celex_num=32002L0032).

However, as regards the elements of the EU legal framework for aquafeed that are set out in regulations, the withdrawal of the UK from the EU had the effect that they no longer applied in that jurisdiction as a matter of either EU or UK law. Consequently, the European Union (Withdrawal) Act 2018 provided that from 1 January 2021 certain directly applicable items of EU legislation, including the regulations relating to aquafeed described in this report would be converted into UK law, with the exception of Northern Ireland which remains in the single market and therefore subject to EU legislation.

Elsewhere in Great Britain, though in accordance with the 2018 act, EU aquafeed legislation, as it applied to the UK on 31 December 2020, is now a part of domestic legislation, including the IUU Regulation. Responsibility for the implementation of this legislation lies with the Food Standards Agency in England, Wales and Northern Ireland and Food Standards Scotland in that country. Now that the UK is no longer a member of the EU, there is clearly potential for aquafeed standards to diverge from those applicable in the EU (with the exception of Northern Ireland). So far this does not appear to have happened.

However, what has most definitely happened is that in terms of EU law, the UK is classified as a third country meaning that imports of aquafeed into the EU are now subject to the provisions on third country imports in the aquafeed regulations.

9. Annex 3 – Species Life History & Production Data

9.1. Atlantic Bluefin tuna

9.1.1. Life history

The Atlantic bluefin tuna is a highly migratory species belonging to the family Scombridae, with a lifespan of about 40 years, reaching a fork length of 3.3 metres and weight of 725 kg. It appears to display a homing behaviour and spawning site fidelity to spawning areas in the Gulf of Mexico and the Mediterranean Sea. There is evidence of other possible spawning areas in the Slope Sea and Cantabrian Sea. It is a multiple batch spawner and a single female of 15-20 years of age can produce up to 45 million eggs. This fish typically occupies the surface and subsurface waters of cold and warm coastal and open seas but has been observed to dive to depths of more than 1,000 metres. It is able to maintain a stable internal body temperature.

9.1.2. Aquaculture production statistics

Atlantic bluefin tuna production in the EU is produced through a ranching method of aquaculture (i.e. the wild capture via purse seine fisheries of juveniles, their transfer to cages, and their ongoing to market size under controlled feeding regime). While experiments have shown feasibility of producing larvae, commercial and large-scale production hatchery production does not exist.

Due to their wild capture, production volumes are typically influenced by quota allocations (governance of tuna fisheries in the EU falls under International Commission for the Conservation of Atlantic Tunas (ICCAT)). Production in Europe started in Spain in 1996 and in Croatia followed by Malta (2000), Italy (2001), Turkey (2002) and Tunisia (2003).

Figure 47 – Trends in global production volumes (t) of Atlantic bluefin tuna by year and country (2013-2023)

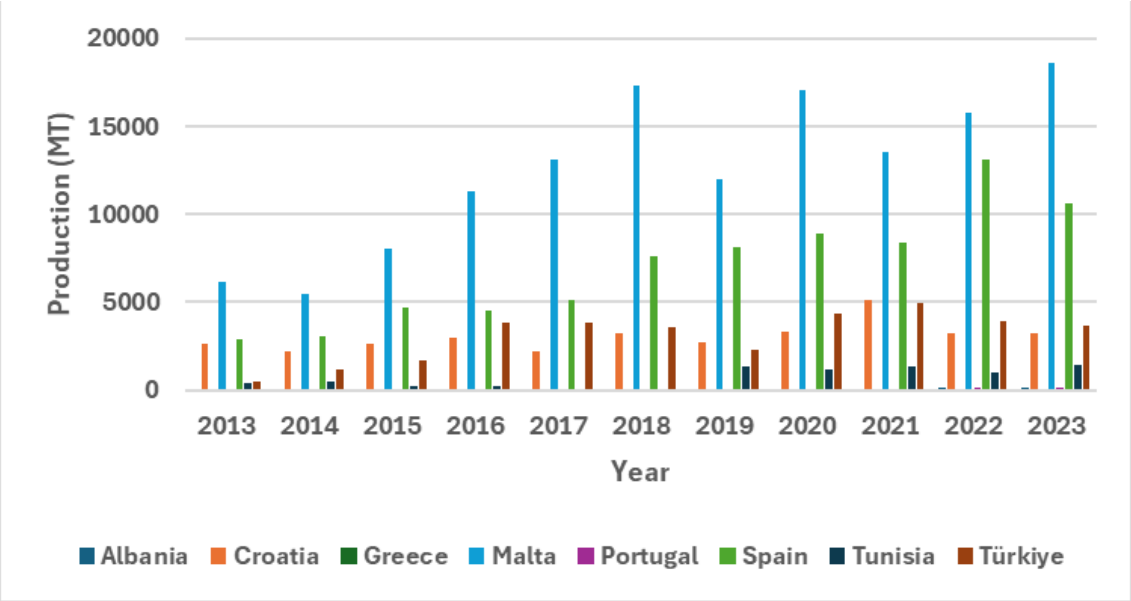


Figure 48 – Global production volume (t) of Atlantic bluefin tuna by year (2013-2023)

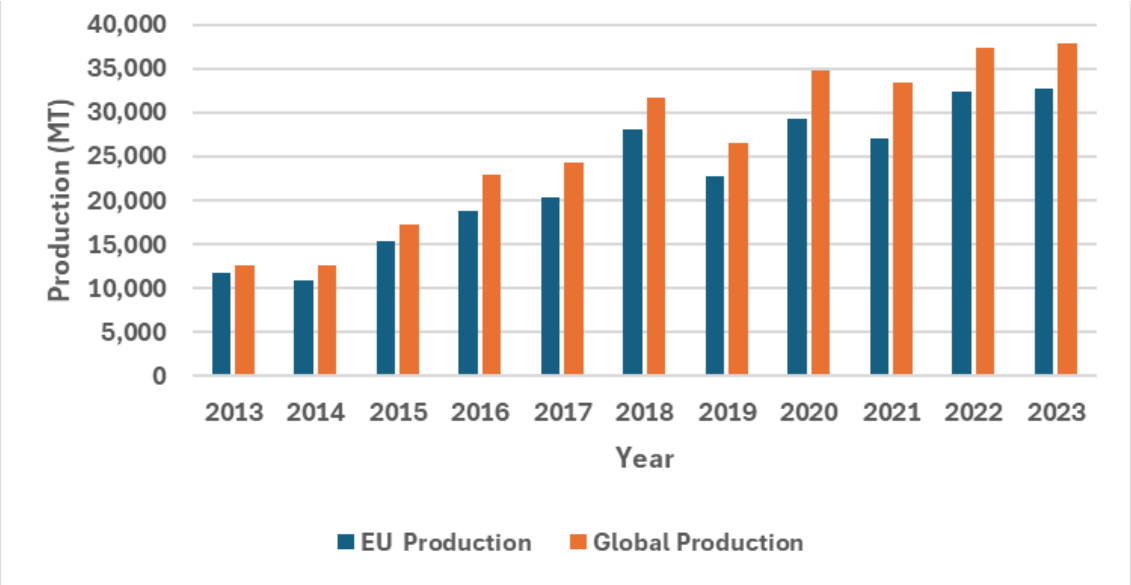


Figure 49 – Total global value (USD million) and value (USD/kg) of Atlantic bluefin tuna (2013-2023)

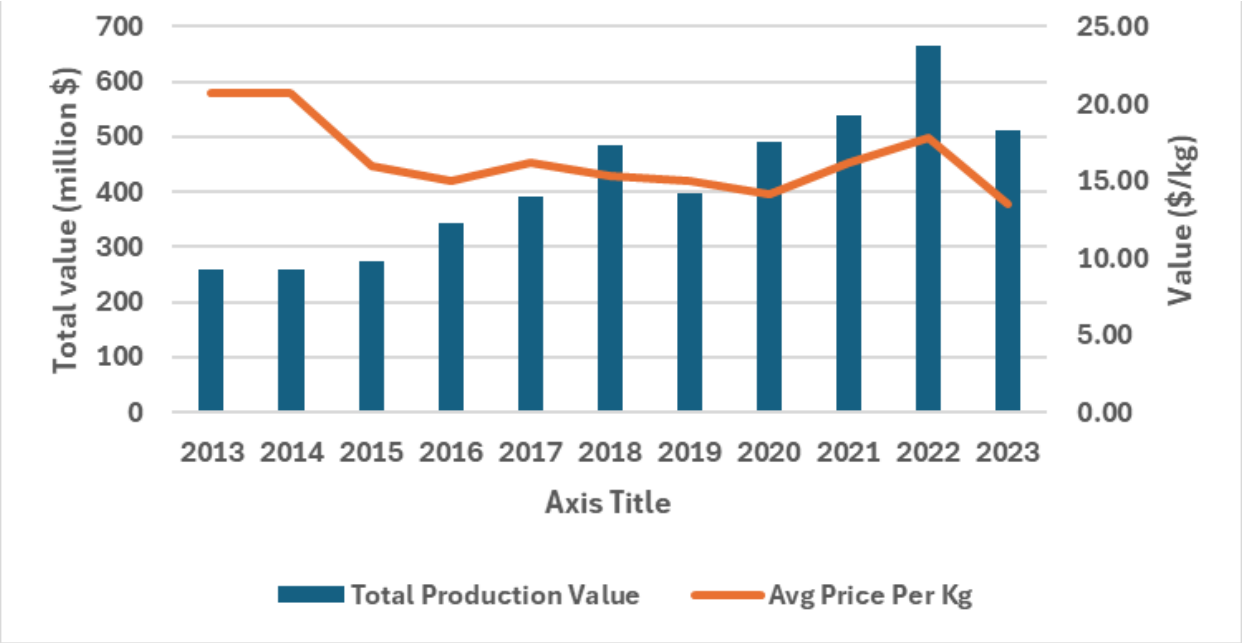


Table 29 – EU production of Atlantic bluefin tuna by country over the period 2013 to 2023

Country	2013	2014	2015	2016	2017	2018
Croatia	2,616	2,224	2,603	2,934	2,162	3,227
Greece	55	75	0	0	0	0
Malta	6,123	5,451	8,051	11,292	13,120	17,326
Portugal	0	0	0	0	0	0
Spain	2,903	3,088	4,691	4,562	5,136	7,575
Total Production (tonnes)	11,697	10,838	15,345	18,789	20,418	28,128

Table 30 – Global production of Atlantic bluefin tuna by country over the period 2013 to 2023 and global value (total and per kg)

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Albania	0	0	0	0	0	0	0	0	0	96	113
Croatia	2,616	2,224	2,603	2,934	2,162	3,227	2,747	3,323	5,104	3,271	3,252
Greece	55	75	0	0	0	0	0	0	0	0	0
Malta	6,123	5,451	8,051	11,292	13,120	17,326	11,970	17,093	13,549	15,816	18,624
Portugal	0	0	0	0	0	0	0	0	0	134	110
Spain	2,903	3,088	4,691	4,562	5,136	7,575	8,108	8,913	8,400	13,145	10,653
Tunisia	380	479	199	218	0	0	1,310	1,194	1,318	997	1,439
Türkiye	470	1,136	1,710	3,834	3,802	3,571	2,327	4,338	4,952	3,879	3,674
Global Production (tonnes)	12,547	12,523	17,254	22,841	24,220	31,699	26,462	34,861	33,322	37,338	37,864
EU % Market Share	93%	87%	89%	82%	84%	89%	86%	84%	81%	87%	86%
Global Production Value	260,256	259,219	275,606	343,059	392,539	485,256	397,106	491,874	538,730	664,863	512,719
Avg Price Per Kg Fish (USD)	$20.74	$20.70	$15.97	$15.02	$16.21	$15.31	$15.01	$14.11	$16.17	$17.81	$13.54

9.1.3. FCR and feed cost calculation

FCR (for adult stages) was calculated by taking averages from the available scientific literature, which equalled to 15 (Ottolenghi, 2008; van Beijnen, 2017; Bridges *et al* 2021; Gamsiz & Korkut, 2022).

The EC’s 2024 Aquaculture Economic Report (STECF, 2025) records feed costs were 24% of total bluefin tuna production costs based on most current data (2022) (reflecting the use of relatively cheap forage fish compared to formulated diets). This equates to an average cost per tonne of feed of EUR 252.

9.1.4. Diet composition

Diet composition is not available because of the feeding practice of feeding various low-value fish species depending on their availability.

9.2. Atlantic salmon

9.2.1. Life history

Atlantic salmon production began in the 19th century and is one of the main marine fish species farmed globally. Rapid increases in production have led to falling prices, which in turn have put increasing pressures on producers to limit costs. As the dominant cost in all aquaculture production, feeding practices have been a key focus on improving efficiency. This has been achieved through continually improving the diet composition to maximise growth (including the use of emerging additives), through the implementation of technology to optimise feeding practices, and through the substitution of expensive feed materials with cheaper alternatives.

Throughout their life cycle, Atlantic salmon are carnivorous; historically, this has placed a dominant requirement on the use of fish meal and fish oil in the diets, however, due to influences of cost, availability, and sustainability, there has been a substantial move to the use of alternative protein sources. This movement has been encouraged by a market of diet manufactures which is consolidated, highly competitive, and driven to innovative in order to maintain market presence. Specifically, this has seen a reduction in fishmeal inclusion in salmon diets from 45% in 1995 to around 12.5% in modern feeds (FAO, 2012; Skretting, 2023).

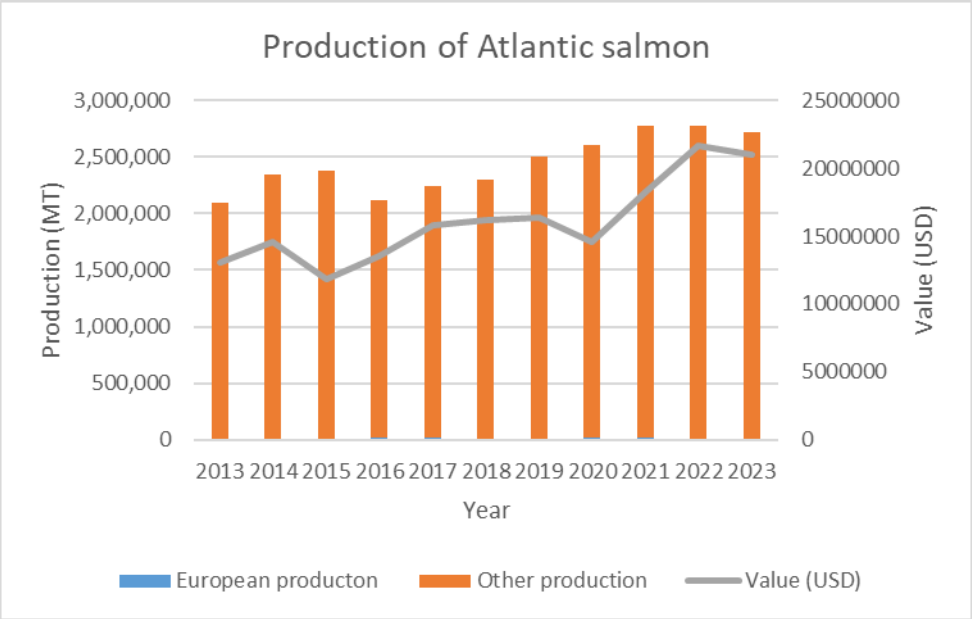
The demand for but the major 3 aquafeed materials – vegetable proteins, vegetable oils and marine proteins (e.g. fishmeal) – were volumes of approximately 735,000, 431,000 and 307,000 tonnes respectively in 2023.

9.2.2. Production statistics and trends

The major global producer of Atlantic salmon is Norway, which currently is responsible for over half of global production (FAO, 2025c); other major producers are Chile and Scotland. The former has experienced substantial variations in production due to disease, which historically has reduced output by 75% (Asche *et al* 2009), however, increased vigilance and biosecurity have improved and stabilized production levels (Negrete, 2024).

Global production of salmon declined year on year from a peak of 2,780,740 tonnes in 2021 to 2,714,650 tonnes in 2023 (12,849 and 10,511 tonnes respectively in the EU).

Figure 50 – Production volume (tonnes) and value (USD) of Atlantic salmon (2013-2023)



Source: FAOFishStatJ (FAO 2025c)
(European production denotes EU-27, non-EU-27 EEA countries and UK)

Table 31 – Global production (tonnes) of Atlantic salmon (2013-2023)

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Australia	42,825	41,591	48,331	56,115	52,580	61,227	56,989	66,918	84,045	81,045	75,287
Bulgaria	0	0	0	0	0	0	0	0	0	0	0
Canada	97,629	86,347	121,926	0	0	0	0	0	0	0	0
Chile	492,329	644,459	608,546	532,225	614,180	661,138	701,984	787,131	725,280	758,953	769,239
Democratic People's Republic of Korea	15	20	20	20	50	60	60	60	60	60	60
Denmark	10	405	428	1,290	808	1,030	1,462	1,940	1,668	1,166	1,222
Faroe Islands	75,821	86,454	80,600	83,300	86,800	78,900	95,000	88,950	115,650	108,630	98,125
Finland	0	0	0	0	0	0	0	0	0	0	0
France	0	0	0	0	0	0	0	0	0	0	0
Greece	0	0	0	0	0	0	0	0	0	0	0
Iceland	3,018	3,965	3,260	8,420	11,265	13,448	26,957	34,341	46,458	44,934	43,523
Ireland	9,125	9,368	13,116	16,300	18,342	11,984	11,333	12,870	12,844	11,916	9,289
Norway	1,168,324	1,258,356	1,303,346	1,233,619	1,236,353	1,282,003	1,364,042	1,388,434	1,562,415	1,564,948	1,542,480
Poland	0	0	4	272	394	493	503	473	500	209	0
Portugal	0	0	0	0	0	0	0	0	0	0	0
Russian Federation	22,500	18,675	10,834	12,857	13,016	20,566	32,343	10,855	14,959	22,084	13,188
Spain	0	4	8	5	24	0	12	0	0	0	0
Sweden	6	8	0	1	0	0	0	0	0	0	0

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Switzerland	0	0	0	0	0	100	159	159	160	160	160
Türkiye	0	0	0	0	0	0	0	0	0	0	0
United Arab Emirates	0	0	0	0	0	0	0	300	180	180	0
United Kingdom	163,240	179,028	171,722	162,817	189,707	156,025	203,881	192,129	205,393	169,194	150,949
United States of America	18,866	18,719	18,719	16,185	14,685	16,491	14,484	16,491	11,127	11,127	11,127
Global production	2,093,708	2,347,398	2,380,859	2,123,426	2,238,205	2,303,465	2,509,209	2,601,052	2,780,740	2,774,606	2,714,650
EU Production	9,141	9,784	13,556	17,868	19,569	13,507	13,310	15,283	15,012	13,291	10,511

9.2.3. FCR, feed demand and feed cost calculation

Feed Conversion Rations (FCRs) were obtained from the scientific literature. For the adult stage an average of two values was used; one reflecting typical FCR between 2013-2016 and another from 2017-2023; both FCRs were taken from scientific papers which calculated them based on *S. salar* production values of Norway, the global leader in Atlantic Salmon production (FAO, 2024a). Juvenile FCRs were averaged from scientific papers; values from control treatments were used to remove treatment effects (Aas *et al* 2019; Aas *et al* 2022; Cook *et al* 2000; Striberny *et al* 2021; STECF (2025).

The EC’s 2024 Aquaculture Economic Report (STECF, 2025) reported that, based on the most current data (2022), feed costs were 32% of total salmon production costs (EUR 108 million) (note: only EU countries are included; Norway and UK are excluded). This equates to a cost per tonne of EUR 2,200. In the same year, Berge (2022) reported the average global cost of salmon feed to be EUR 1,300/tonne. The average of both these values – EUR 1,750 – was used to develop the figures below.

Table 32 – Aquafeed demand of Atlantic salmon (adult) 2013-2023 in the EU

Country (Name)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Bulgaria	0	0	0	0	0	0	0	0	0	0	0
Denmark	13	506	535	1,613	1,042	1,329	1,886	2,503	2,152	1,504	1,576
Finland	0	0	0	0	0	0	0	0	0	0	0
France	0	0	0	0	0	0	0	0	0	0	0
Greece	0	0	0	0	0	0	0	0	0	0	0
Ireland	11,406	11,710	16,395	20,375	23,661	15,459	14,620	16,602	16,569	15,372	11,983
Poland	0	0	5	340	509	636	649	611	645	269	0
Portugal	0	0	0	0	0	0	0	0	0	0	0
Spain	0	5	10	6	31	0	15	0	0	0	0
Sweden	8	10	0	1	0	0	0	0	0	0	0
Total EU Species Feed Demand	11,426	12,622	17,487	23,050	25,244	17,424	17,169	19,716	19,366	17,145	13,559
Global Species Feed Demand	2,617,135	3,028,143	3,071,308	2,739,220	2,887,285	2,971,470	3,236,880	3,355,357	3,587,154	3,579,242	3,501,898

Table 33 – Total feed demand (tonnes) for juvenile Atlantic salmon (2014-2023)*

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Denmark	16	19	26	33	36	35	43	66	64	29
Germany					36					
Estonia	18									
Ireland	304	304	351							
Spain	3	3	3				1	1		
Poland	29	1	2	2	74	140	150	93	103	97
Finland	152	152	101	152	253	304	203	203	218	217
European Union total	522	479	483	187	399	479	397	363	385	343

** Based on juvenile weight of 46.5g (Cook et al 2000; Striberny et al 2021)*

9.2.4. Diet composition

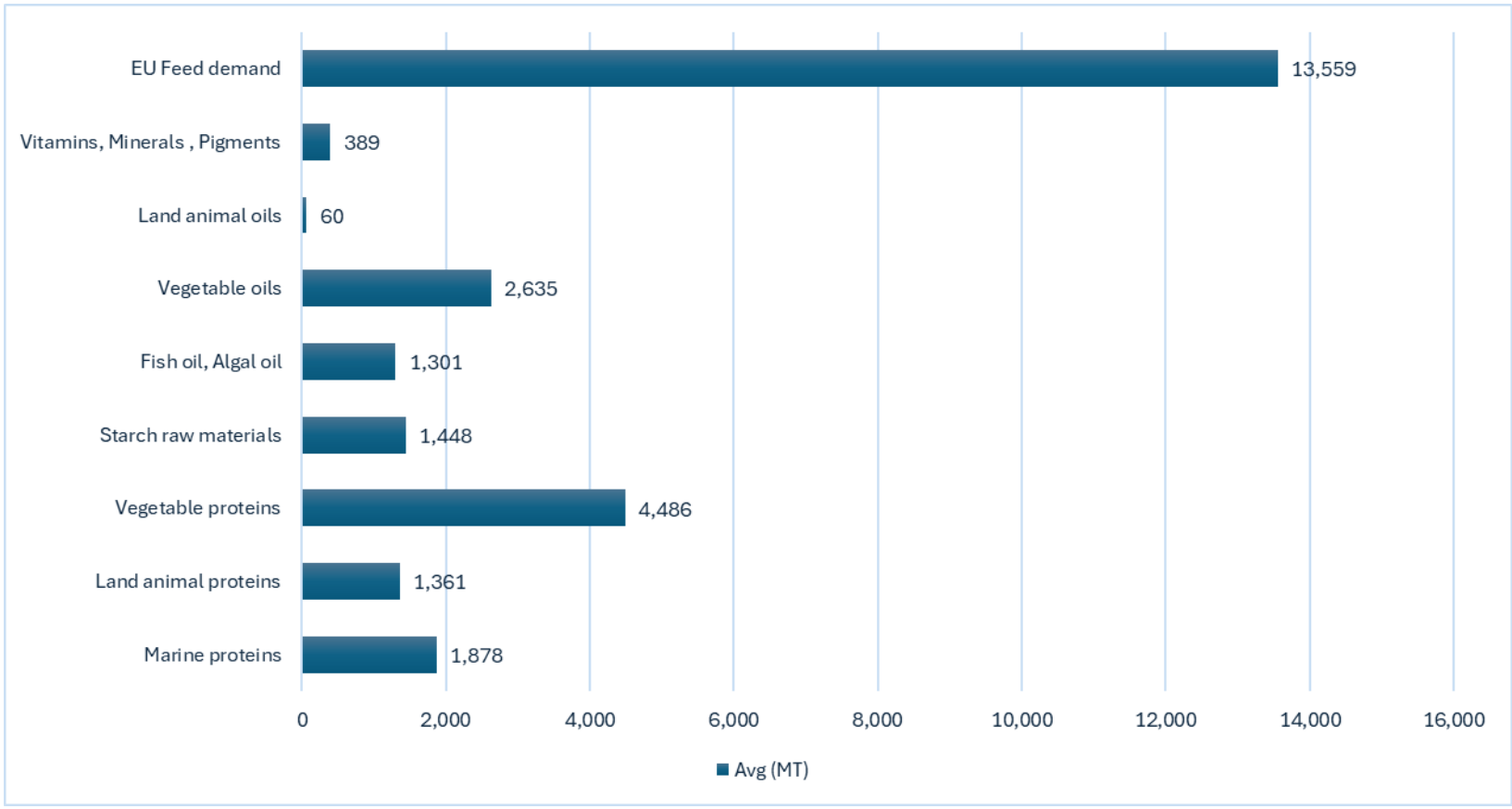
Table 34 – Indicative diet composition of Atlantic salmon aquafeeds

Category	Material (for adult stages)	% inclusion[1]	Material (for juvenile stages)	% inclusion[2]
Vegetable protein sources	Soy protein concentrate	20.9	Pea protein concentrate	9
	Wheat gluten	9.8	Faba bean dehulled	4.8
	Guar protein	4.3	Soy protein	15.5
	Sunflower	3.4	soy protein concentrate	26.5
	Pea protein	1.4	Wheat gluten	3.5
	Maize gluten	0.7		
Vegetable oils	Rapeseed oil	18	Rapeseed oil	8.5
	Linseed oil	1.3		
	Soybean oil	0.4		
	Camelina oil	0.4		
	Coconut oil	0.1		
Carbohydrate sources	Wheat	6.5	Wheat	15-18.9
	Faba beans	3.6	Sunflower meal	5
	Pea flour	2.5	Potato starch	5
Marine protein sources	Fish meal, forage fish a	8.8	Fish meal	25-59.7
	Krill meal	0.3		
	Fish meal, cut-offs	3.3		
Marine oils	Fish oil, forage fish	8.3	Fish oil	8.5-11.2
	Fish oil, cut-offs	2		

Category	Material (for adult stages)	% inclusion[1]	Material (for juvenile stages)	% inclusion[2]
Micro materials	Astaxanthin	0.01	Vitamin and mineral premixes	1.1-1.75
	Vitamin and mineral	4.1	Lecithin	0.5
	Probiotics/prebiotics	0.03	Astaxanthin	0.05
	Functional materials	0.5-1	Choline chloride	0.2
			Methionine	0.1
			Functional materials	0.05-1

Source: 1. Adult diets based on Aas et al. (2019), Aas et al. (2022), Jaramillo-Torres et al. (2019). 2. Juvenile diets based on Cook et al. (2000), Streberny et al. (2021), Sissener et al. (2021).

Figure 51 – Estimated EU demand for Atlantic salmon (tonnes) (2023)



Source: Average taken from minimum and maximum estimates from Cargill (2023) and Skretting (2023)

9.3. Common carp

9.3.1. Production trends and statistics

Global aquaculture production of common carp has remained stable in recent years, with annual volumes ranging between 4.1 and 4.2 Mt in the early 2020s (FAO, 2024a). Common carp is ranked among the top five aquaculture species worldwide in terms of production volume, highlighting its significance as a staple food fish in global aquaculture (Eurostat, 2025). The production landscape is heavily dominated by Asian countries, with China accounting for approximately 70% of the total global output. Other major producers include Indonesia, India, and Bangladesh, underscoring Asia’s pivotal role in carp aquaculture (FAO, 2024a; EUMOFA, 2021b). Despite fluctuations in production in individual countries, the global supply of common carp has demonstrated relative stability, reflecting consistent demand across key markets in Asia.

In contrast, the European Union holds a minor position in the global carp sector. The total EU production of common carp representing just about 2% of the global total (EUMOFA, 2021a). Carp holds a strong cultural position in Central Europe, particularly as a traditional Christmas Eve dish in Catholic countries. It remains the most important cyprinid species in earthen pond aquaculture. The sector is characterized by low-intensity, pond-based farming systems, with a significant share of production occurring in polyculture. This approach typically combines carp with other species such as grass carp, silver carp, and predatory fish like pike-perch, taking advantage of natural food sources in a multi-trophic system. Beyond their production function, carp ponds play a vital role in water retention, hydrodynamic regulation, microclimate stabilization, and biodiversity conservation — many of these areas overlap with protected zones such as the Natura 2000 network. Production volumes of common carp in the EU have remained relatively stable across Europe, averaging around 65,000 tonnes annually between 2008 and 2022. In 2022, EU production stood at 62.5 thousand tonnes, with Poland and the Czech Republic accounting for 54% of the total output. While countries like Poland, the Czech Republic, and Hungary have maintained stable or slightly increasing production levels, others, including Germany and Romania, have seen significant declines. Overall, carp production is concentrated in ten EU countries, with six exceeding 2,000 tonnes per year. (STECF, 2025).

Figure 52 – Production volume (tonnes) and value (USD) of common carp (adult)

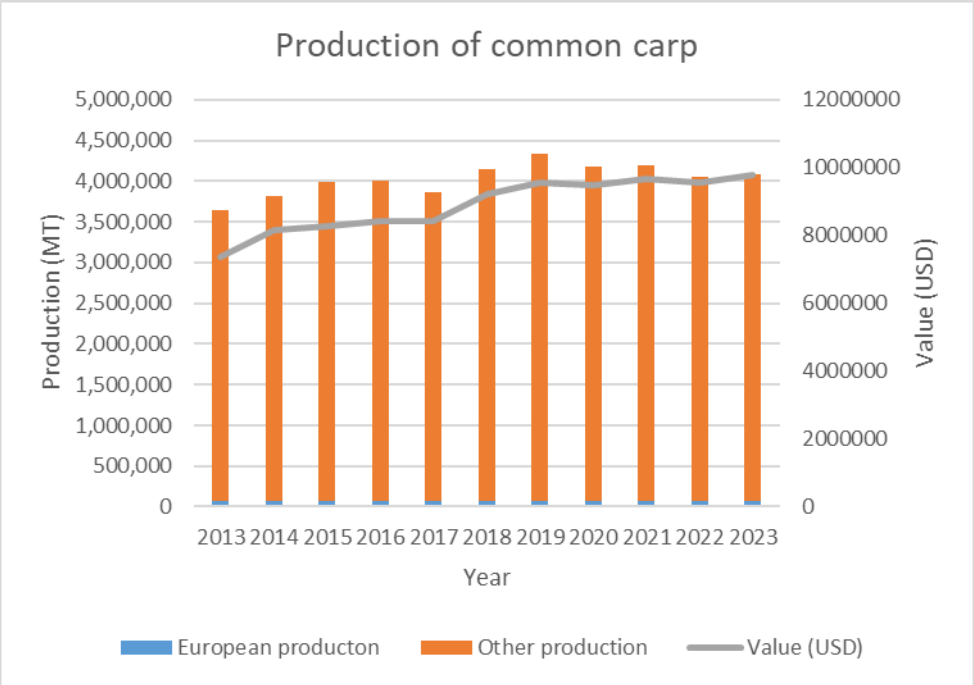


Table 35 – Production volume (tonnes)* of common carp in EU-27 countries

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Global	3,819,035	3,993,698	4,008,025	3,862,885	4,146,694	4,331,156	4,173,433	4,192,020	4,053,062	4,091,350
EU-27	71,328	69,181	70,979	71,774	67,472	69,488	69,268	65,719	62,488	63,430
Bulgaria	1,885	2,142	2 508	2 303	2 363	2 989	2 543	2 456	2 434	2 781
Czechia	17,833	17,860	18 354	18 460	18 429	17 945	17 370	17 616	16 437	15 903
Germany	5,285	4,916	5 238	4 597	4 746	4 641	4 788	4 610	4 131	4 056
Estonia			34			30				
Greece		14	6	7	0	0	16	0	8	46
France	4,200	4,200	4 200	4 200	1 417	1 415	1 409	1 270	1 338	2 006
Croatia	2,284	3,401	2 698	2 039	1 959	2 037	1 691	2 828	2 459	2 294
Italy	134	220		156	155	192	139	199		184
Latvia		549	569	606	489	513	541	563		
Lithuania	2,900	3,401	3 252	2 710	2 701	2 742	2 937	3 392	2 811	2 144
Hungary	10,291	10,725	10 321	12 240	11 462	11 436	11 909	11 309	11 352	11 037
Austria	573	618	607	620	647	619	621	617	560	557
Poland	18,368	16,223	17 400	16 851	16 478	18 376	19 733	15 893	16 698	17 697
Romania	3,737	4,349	4 841	4 539	4 357	4 110	3 647	3 231	3 062	3 061
Slovenia	134	127	150	123	109	113	133	126	124	122
Slovakia	241	258	357	556	340	703	593	336	538	589

Source: Eurostat Aquaculture production by species. (2025). For Germany, due to the lack of Eurostat data, FAO data (2025c) were used.
*Production from aquaculture excluding hatcheries and nurseries

Table 36 – Production (million individuals) of juvenile common carp across EU-27 countries

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU-27	653.0	687.3	733.1	710.7	617.2	609.0	440.8	727.8	575.8	337.7
Austria	0.4	0.4	0.6	0.6	0.6	0.5	0.9	1.0	0.4	0.2
Bulgaria	2.9	3.2	3.7	5.7	3.2	4.6	3.7	0.6	0.8	0.9
Croatia	110.0	96.5	99.3	101.7	16.8	20.7	22.7	34.7	34.9	23.2
Czechia	273.6	326.2	327.5	277.3	293.3	264.3	184.0	346.4	245.9	37.3
Germany	44.0	42.5	81.1	56.7	60.9	56.0	55.8	65.8	59.1	43.6
Greece	0.3					0.0			0.0	0.0
Hungary	22.4	26.3	24.9	25.8	28.4	24.3	20.2	29.6	21.0	2.2
Italy	3.2	4.8	3.4	3.5	3.5	3.8	6.5	4.0	4.0	
Latvia	18.2	3.0	0.0				0.0	0.0	0.0	0.0
Lithuania	9.8	5.3	6.3	12.6	11.4	3.4	3.0	3.8	5.0	8.5
Poland	163.1	176.6	175.3	181.9	184.1	189.3	140.8	232.2	202.7	220.1
Romania	2.9	0.8	9.2	43.3	13.8	39.9	1.3	8.1	0.4	0.9
Slovakia	2.1	1.6	1.9	1.7	1.3	2.3	1.9	1.5	1.7	0.8
Spain	0.2	0.1								

9.3.2. FCR, feed demand and feed cost calculation

~75% of the EU production place under semi-intensive systems, relying on natural food sources supplemented with plant-based feeds (mainly cereals such as lupin, wheat, barley and maize, as well as sunflower meal, rapeseed meal and potatoes), with FCRs for these feeds ranging from 4-8. Based on data from the EU DCF for Poland, it is estimated that approximately 25% of carp production is carried out using extruded (complete) feeds, for which the average FCR is approximately 1.75 for adults (Dmuchowski, 2023, Mocanu, 2015) and 1.35 for juveniles (Hoseinifar *et al* 2016; Sultana *et al,* 2001). Carp juvenile production is highly diverse and includes light fry, heavy fry, and one-summer carp fingerlings.

Production data indicate fluctuations in annual output reflecting varying producer strategies influenced by climatic conditions. Carp juveniles feed on natural food sources and are supplemented with both plant-based feeds and complete (extruded) feeds. However, it is not possible to provide any quantified estimate of fry feed demand for carp based on the available statistical data. As for production of edible carp roe, it remains a niche product, only in some countries as Romania. Due to Eurostat (2025a) aquaculture production by species production level is close to zero, so the volume of carp farmed for roe does not have a quantitative impact on feed demand in carp aquaculture.

The cost of carp feed was taken as an average from the economic case study of Mihály-Karnai *et al* (2025). Using two complete diets, the average cost of food was EUR 993/t.

Table 37 – Feed demand (tonne) of carp (juveniles*)

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU-27	4,002	4,212	4,493	4,356	3,783	3,733	2,702	4,461	3,529	2,070
Bulgaria	18	20	23	35	20	28	23	4	5	6
Czechia	1,677	1,999	2,007	1,700	1,798	1,620	1,128	2,123	1,507	229
Germany	270	260	497	348	373	343	342	403	362	267
Greece	2									
Spain	1	1								
Croatia	674	591	609	623	103	127	139	213	214	142
Italy	20	29	21	21	21	23	40	25	25	
Latvia	112	18								
Lithuania	60	32	39	77	70	21	18	23	31	52
Hungary	137	161	153	158	174	149	124	181	129	13
Austria	2	2	4	4	4	3	6	6	2	1
Poland	1,000	1,082	1,074	1,115	1,128	1,160	863	1,423	1,242	1,349

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Romania	18	5	56	265	85	245	8	50	2	6
Slovakia	13	10	12	10	8	14	12	9	10	5

* Based on juvenile weight of 4.54g (Hoseinifar *et al* 2016; Sultana *et al,* 2001)

Table 38 – Pelleted Feed demand of carp (adults) 2013-2023

Country (Name)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Austria	271	251	270	266	271	282	271	271	270	245	244
Belgium	-	-	-	-	-	-	-	-	-	-	-
Bulgaria	1,575	1,066	937	1,168	1,577	1,705	1,822	1,413	1,399	1,061	1,217
Croatia	919	999	1,488	1,180	892	857	891	740	1,237	1,076	1,003
Czechia	7,354	7,802	7,814	8,030	8,076	8,063	7,851	7,599	7,707	7,191	6,958
Denmark	0	0	-	-	-	-	-	-	-	-	-
Estonia	19	15	-	15	-	-	13	-	-	7	-
France	1,838	1,838	1,838	1,750	1,750	651	619	617	549	433	861
Germany	2,493	2,312	2,151	2,292	2,011	2,076	2,030	2,095	2,017	1,807	1,775
Greece	18	12	6	2	3	-	-	0	0	3	20
Hungary	4,214	4,502	4,692	4,391	5,355	5,015	5,003	5,232	5,020	4,966	4,829
Italy	40	59	57	237	237	68	83	61	87	-	81
Latvia	229	222	240	249	265	214	224	237	246	266	247
Lithuania	1,641	1,446	1,605	1,520	1,287	1,276	1,363	1,448	1,579	1,321	1,113
Poland	8,208	8,882	7,098	7,612	7,372	7,209	8,040	8,633	6,953	7,305	7,743
Romania	1,485	1,635	1,903	2,118	1,986	1,906	1,834	1,596	1,414	1,340	1,339
Slovakia	95	105	113	159	262	149	307	305	219	263	270
Slovenia	54	59	55	66	54	48	49	58	55	54	53
Spain	1	1	1	0	1	-	1	-	-	-	-
Sweden	-	-	-	-	-	-	-	-	-	-	-

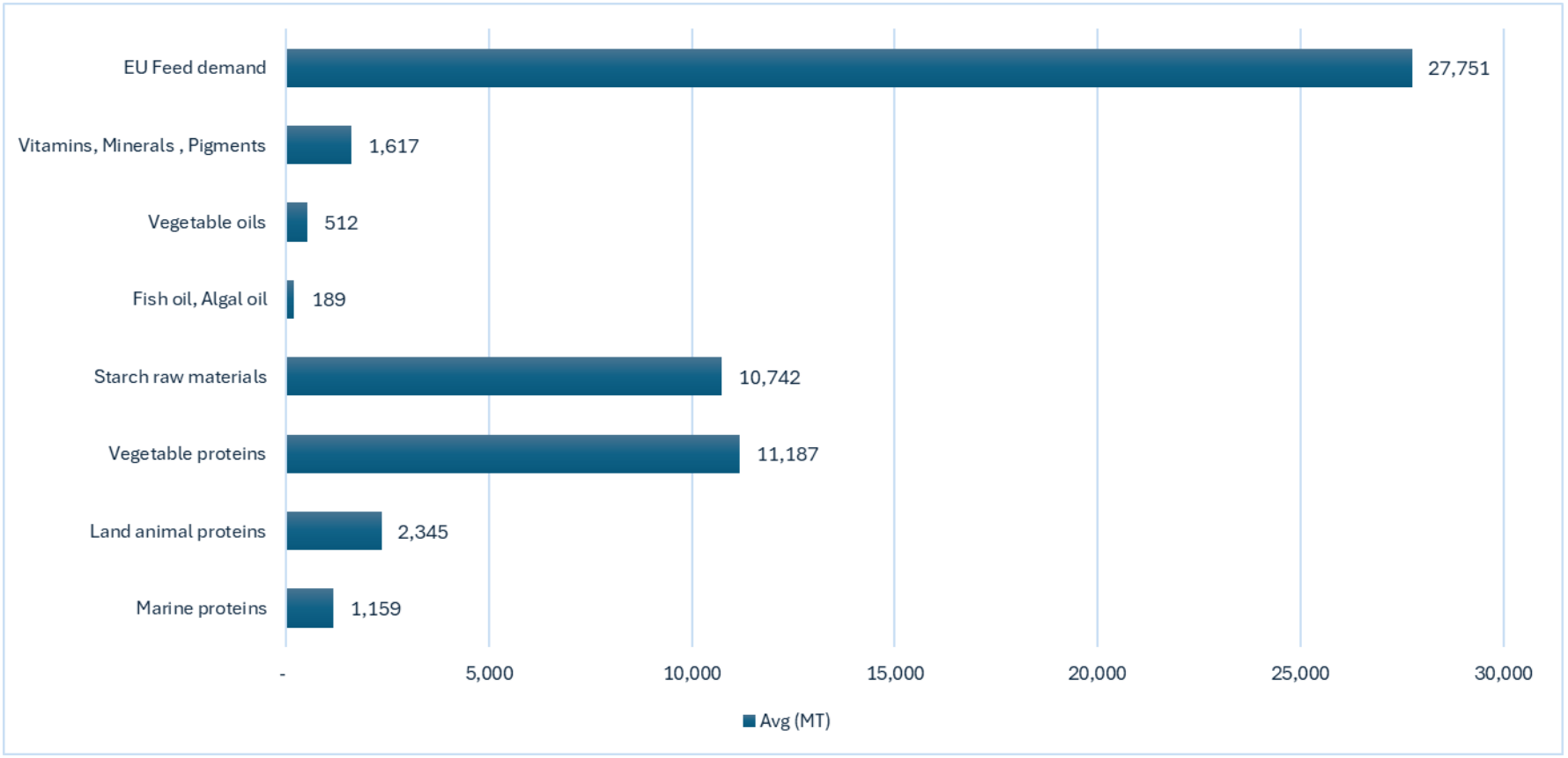
Country (Name)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU Species Feed Demand	30,453	31,206	30,267	31,053	31,401	29,519	30,401	30,305	28,752	27,339	27,751
Global Species Feed Demand	1,595,219	1,670,828	1,747,243	1,753,511	1,690,012	1,814,179	1,894,881	1,825,877	1,834,009	1,773,215	1,789,966

9.3.3. Diet composition

Table 39 – Indicative diet composition of common carp aquafeeds

Category	Material
Vegetable protein sources	Lupins
	Plant proteins
	Soy (soya)
	Rapeseed (cake/expeller/meal)
	Sunflower protein concentrate
	Sunflower meal / Sunflower cake/expeller
	Lupins
Vegetable oils	Vegetable oils
	Rapeseed oil
Carbohydrate sources	Cereal products (grains)
	DDGS (distillers grains)
	Maize (Corn)
	Barley
	Wheat
	Triticale
	Oats
Marine protein sources	Fish meal
	Krill meal
	Marine by-products
	Triticale (hybrid grain)
Land protein sources	Blood meal
	Feather meal
	Haemoglobin meal (blood protein)
	Non-marine by-products
	Poultry meal
	Processed animal proteins
	Single-cell proteins
Marine oils	Fish oil
Land based oils	Processed animal oils/fats
Micro materials	Vitamins and minerals

Figure 53 – Estimated EU feed material demand for common carp (tonnes) (2023)



Source: Average taken from minimum and maximum estimates from Cargill (2023) and Skretting (2023)

9.4. European seabass

9.4.1. Life history

Dicentrarchus labrax is euryhaline, frequently found in coastal inshore waters, estuaries and brackish water lagoons. The osmoregulatory capacity increases as development progresses under natural conditions in coastal zones. Early development of European seabass occurs in seawater and only after they reach a size of about 2 cm do they exhibit greater osmoregulatory capacity and migratory movements toward estuaries. They have also been occasionally spotted venturing upstream into freshwater (Frimodt, 1995). While they are considered eurythermic, they demonstrate higher growth at temperatures above 18°C. Young fish form schools, whereas adults are less gregarious.

They can reach up to 70 cm in length and a body weight of 6 kg. In the wild, males attain sexual maturity between 2 to 4 years in the Mediterranean and between 4 to 7 years in the Atlantic (30 to 40 cm in length). Females reach sexual maturity at ages 5 to 8 years (36-46 cm in length). Annual spawning occurs during winter or early spring. They have a single breeding season each year, which takes place in the winter from December to March for the Mediterranean populations and up to June for the Atlantic populations. European seabass commonly spawns near river mouths, estuaries or littoral areas where there is high salinity (≥30‰). Since they do not present sensitivity to the water temperature they may be found spending the winter in coastal lagoons instead of the open sea. They are predominantly carnivorous in the wild where juveniles (SL <30 mm) have been found to feed mainly on copepods and nauplii of Cirripedia, while bigger juveniles (SL about 60 mm) feed on larger prey, particularly larvae of Decapoda and Mysidacea (Ferrari and Chieregato, 1981). Adult seabass is known for their piscivorous habits, including cannibalistic feeding behaviour with seasonal fluctuations (Henderson and Corps, 1997). They generally exhibit diurnal feeding patterns, with increased activity during dawn and dusk.

The European seabass was the first marine non-salmonid species to be commercially cultured in Europe. Initial attempts at culturing this species took place in tidal reservoirs and coastal lagoons. Fish culture was associated with salt production in coastal evaporation pans and marshes. During the summer and autumn, when evaporation rates were high, salt was harvested, and fish were cultured during the winter and spring. To support this endeavour with European seabass juveniles, schools of fish were trapped from estuarine areas. During the late 1960s, France and Italy competed to develop reliable mass-production techniques for seabass juveniles, achieving considerable success

that allowed many Mediterranean countries to provide healthy larvae (FAO, 2009a).

9.4.2. Production, production trends and statistics

Growth of seabass larvae can present considerable variation depending on hatchery best practices as well as the time of weaning on to compound feeds. It takes around four months to produce 2 g fry starting from viable larvae at a water temperature of 18 to 20°C (Hatziathanasiou *et al* 2002). From the hatcheries, the young juveniles are transferred to pre-growing cage farms and after samplings, screenings and sorting they are placed to the grow-out cages until they reach a commercial size (300-400 g) in about 24 months (Kaushik, 1998; Lupatsch *et al* 2001), although in Eastern Mediterranean this period is much shorter (15-18 months).

In 2013, EU Countries produced around 64,000 tonnes of European seabass, accounting for up to 43% of the global market share. EU countries maintained their Market share until 2016 when it started to decline each year reaching 30% with over 86,000 tonnes in 2023. Over a ten-year period, overall production increased by 24%, contributing among other factors to the loss of market share.

As of 2023, Greece is the largest European seabass producer, with approximately 44,000 tonnes, followed by Spain and Croatia with 24,400 and 8,500 tonnes respectively. Similar to gilthead seabream, Türkiye has emerged as the main contributor to market growth for this species over the past decade, significantly expanding its farming capabilities from 68,000 tonnes in 2013 to 160,800 tonnes in 2023.

The overall value of European seabass has doubled, increasing from approximately USD 900 million in 2013 to USD 1.8 billion in 2023. This growth is largely attributed to increased production, as prices, while fluctuating, have not significantly risen.

Figure 54 – EU and Global production (European seabass) in tonnes (tonnes) over a ten-year period

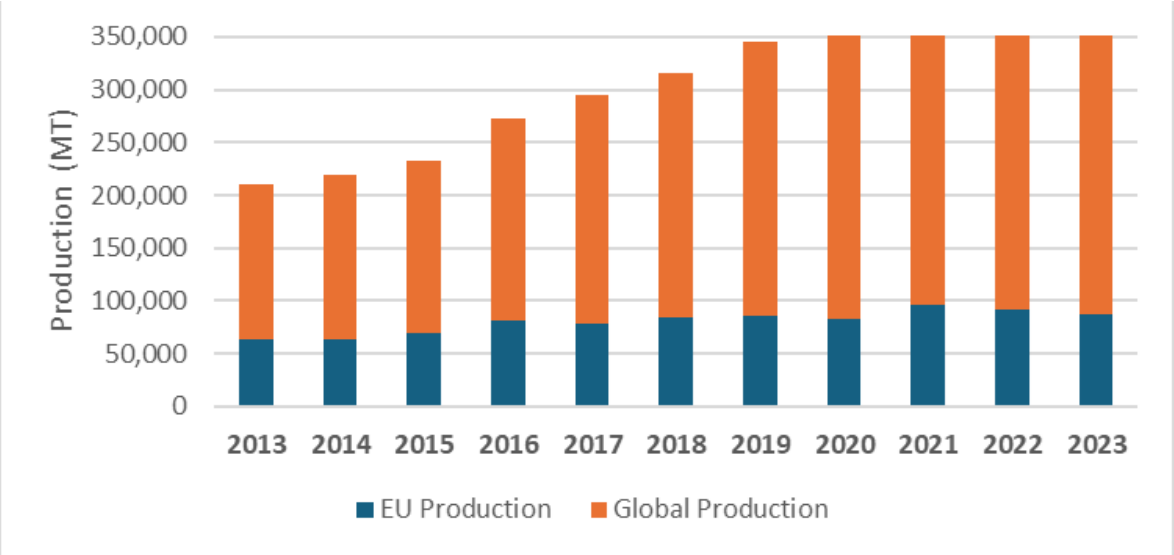


Figure 55 – Top EU European seabass producing countries in 2023

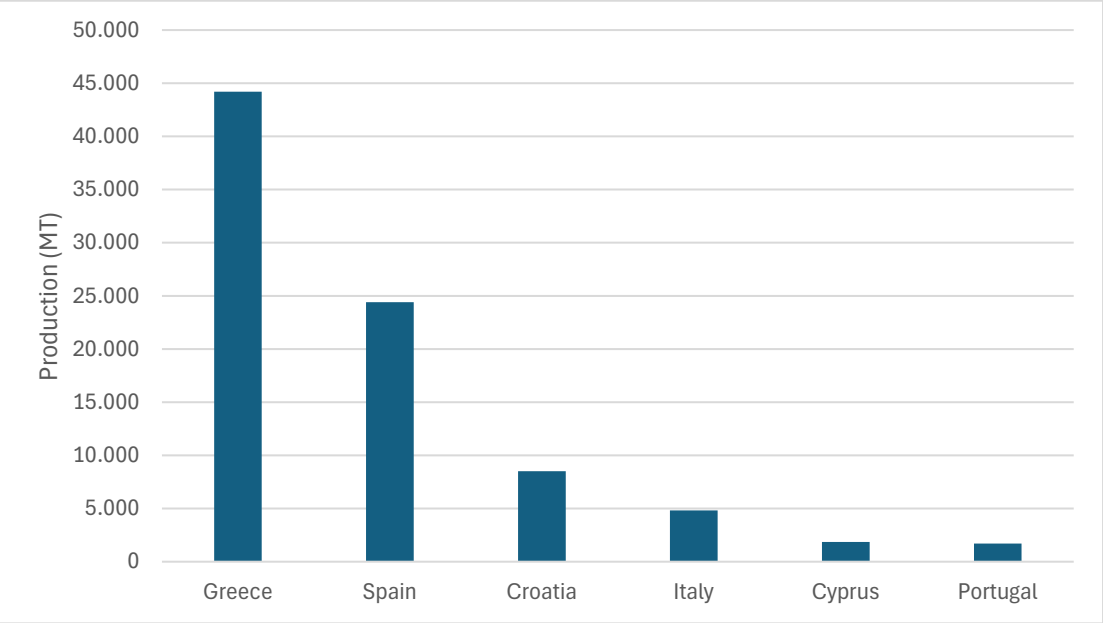


Figure 56 – European seabass global production value and average fish price per kilo over a ten-year period

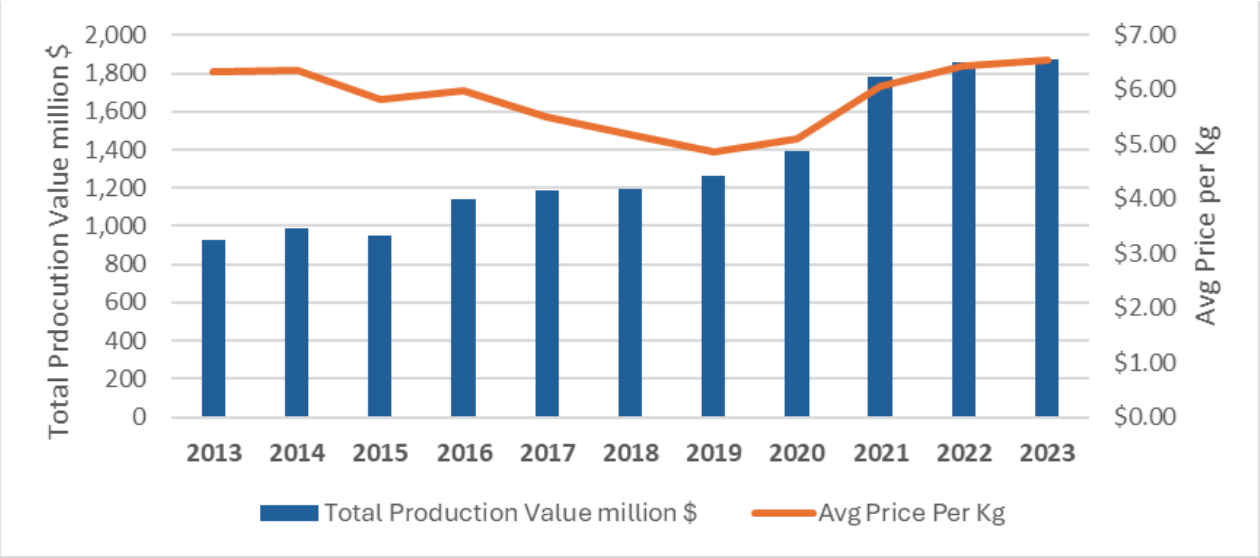


Table 40 – Production EU of Seabass (tonnes) 2013-2023

Unit (Name)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Croatia	2,826	3,215	4,488	5,310	5,616	6,220	6,089	6,754	9,083	10,034	8,515
Cyprus	1,422	1,817	1,726	1,517	2,254	2,389	2,836	2,924	2,680	1,959	1,854
France	2,428	2,244	2,156	1,750	1,400	1,722	2,461	2,376	1,250	1,080	966
Germany	0	0	0	0	0	0	0	0	0	0	
Greece	34,920	32,142	36,600	42,479	44,285	46,911	41,237	40,763	51,232	47,145	44,201
Italy	6,330	5,724	5,800	6,800	6,800	5,738	7,420	6,153	7,277	4,972	4,819
Malta	127	190	27	39	59	77	62	136	221	139	15
Portugal	575	455	295	403	701	200	675	904	834	1,481	1,703
Slovenia	50	66	70	70	80	80	80	50	38	49	60
Spain	14,945	16,722	18,600	22,956	17,656	21,269	25,260	22,765	23,037	24,121	24,413
Total Species Production	63,624	62,575	69,763	81,325	78,850	84,605	86,119	82,825	95,652	90,980	86,546
Global Species Production	147,202	155,924	163,439	191,340	215,572	231,023	259,876	273,509	293,231	288,173	286,968

9.4.3. FCR, feed demand and feed costs calculation

Feed demand was estimated by taking into account the average FCR of European seabass for the entire production cycle. Abdou *et al* (2017) reported an overall FCR of 1.88 after rearing 4 g seabass juveniles for 18 months.

García *et al* (2019) conducted a trial lasting approximately 20 months, noting an FCR of juveniles from 0.5 g to 15 g was 1.5 and from 15 g to 500 g, 1.9. Aubin *et al* (2009) documented an FCR of 1.77 in a 16-month trial, starting with fish at 2g and growing to a market size of 350 g. Additionally, Jerbi *et al* (2012) conducted a 24-month feeding trial from the hatchery stage to the grow-out cage stage, reporting an FCR of 2.08 with an average weight of 375 g. Finally, Konstantinidis *et al* (2021) indicated that in a 24-month feeding trial the average FCR is 2.14. For the purposes of this study, by combining the information provided by these authors and personal communication with various aquaculture units, we assume an average FCR of 2. Similarly, the FCR of juvenile fish, taken as an average from the findings of Roncarati et al. (2001) was 2.03.

The Hellenic Aquaculture Producers Organisation (HAPO, 2024) provide average food prices per year, which were used in the calculation of estimated value of feed.

Seabass, seabream, sole, meagre all share similar larval/juvenile requirements so a similar approach was taken when estimating their live food requirements: All these species have a substantial phase of live food consumption (typically rotifers then Artemia)- which is phased with inert feeding. To estimate this demand, the number of rotifers and artemia were calculated by multiplying the number of larvae by 120 or 130, which is the estimated (min/max) mass (kg) of Artemia consumed per larvae. The quantity of Artemia enrichment product was estimated on the basis that 36L of enrichment is used per million larvae produced. During the inert feeding stages, the kg of manufactured feed was estimated on the basis that 1 million fry consume 40-60 kg (min/max) of formulated diet during the co-feeding stage, 250-350 kg during weaning, and 2,010-2,090 kg during nursery stages. All estimates were obtained after interviews with hatchery managers and fish feed companies (who asked to remain anonymous given the sensitivity of the data). Quantity of broodstock feed was calculated as the kg of feed (a range) that is needed to produce 1 million of larvae. For example, for seabass and seabream this is between 80 to 120 kg of feed. However, some hatcheries still use frozen diets (e.g. squid) whereas others are not using frozen products in order to avoid ichthyopathological issues.

Table 41 – Indicative diet composition of European seabass

Raw Material Category	Larvae Materials	Juvenile - Grower Materials
Vegetable protein sources	Maze gluten, Wheat gluten and Soy protein Concentrate	Soya meal, Sunflower cake/expeller, Maze gluten, Soy protein concentrate, Rapeseed meal, Lupin meal and Faba beans
Vegetable oils	Refined palm oil	Rapeseed oil, Soybean oil and Camelina oil
Carbohydrate sources	Wheat starch, Wheat Flour	Wheat Flour, Dry Distillers Grains with Solubles (DDGS)
Marine protein sources	Fish meal, Krill meal, Squid meal and Hydrolyzed fish protein	Fish meal, Krill meal, Squid meal and Hydrolyzed fish protein
Land protein sources	Blood meal and Whey protein	Blood meal, Hydrolyzed feather meal, Poultry meal, Hemoglobin powder and Whey protein
Land oil sources	-	Poultry oil
Single cell proteins	Dried algae (*Haematococcus pluvialis, Schizochytrium limacinum*), brewers yeast (*Saccharomyces cerevisiae*).	Dried algae (*Haematococcus pluvialis, Schizochytrium limacinum*), brewers yeast
Marine oils	Fish oil and Algal oil	Fish oil and Algal oil
Micro materials (Antioxidants, Preservatives , Additives, Minerals, Vitamins, Probiotics)	Antioxidants (BHA, BHT, Propyl gallate and Citric acid)	Antioxidants (BHA, BHT, Propyl gallate and Citric acid)
	Preservatives (Sorbic acid, Calcium propionate, Orthophosphoric acid and Sodium Propionate)	Preservatives (Sorbic acid, Calcium propionate, Orthophosphoric acid)
	Additives (Herb extracts, Fish gelatin, Lecithin, Phospholipids)	Additives (Herb extracts, Fish gelatin, Betaine, Lecithin, Phospholipids)
	Vitamins (A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, Choline chloride)	Vitamins (A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, Choline chloride, Inositol)
	Minerals (Phosphorus, Calcium, Iron, Iodine, Copper, Manganese, Selenium and Zinc)	Minerals (Phosphorus, Calcium, Iron, Iodine, Copper, Manganese, Selenium and Zinc)
	Amino acids (Methionine)	Amino acids (Lysine, Methionine and Threonine)
	Probiotics (*Pediococcus acidilactici*)	Probiotics (*Pediococcus acidilactici*)

Table 42 – Total quantity (EU) of diets for European seabass (juveniles) (2014-2023)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Rotifers Min (billion)	4741	4008	3805	3591	6521	6178	4509	5163	4150	4872
Rotifers Max (billion)	7902	6681	6341	5986	10868	10296	7515	8605	6917	8120
Enrichment Rotifers Min (L)	2766	2338	2219	2095	3804	3604	2630	3012	2421	2842
Enrichment Rotifers Max (L)	7902	6681	6341	5986	10868	10296	7515	8605	6917	8120
Artemia small (Kg cysts) -not enriched (Min)	3951	3340	3171	2993	5434	5148	3758	4303	3459	4060
Artemia small (Kg cysts) -not enriched (Max)	7111	6013	5707	5387	9781	9267	6764	7745	6226	7308
Artemia large enriched (kg cysts) (Min)	47410	40085	38047	35914	65210	61778	45092	51633	41504	48718
Artemia large enriched (kg cysts) (Max)	51360	43425	41218	38906	70644	66926	48850	55935	44962	52777
Enrichment Artemia products (L)(Min)	14223	12025	11414	10774	19563	18533	13528	15490	12451	14615
Enrichment Artemia products (L) (Max)	20544	17370	16487	15563	28258	26770	19540	22374	17985	21111
Co-feeding (200-300 µm) Kg compound diet Min	15803	13362	12682	11971	21737	20593	15031	17211	13835	16239
Co-feeding (200-300 µm) Kg compound diet Max	23705	20042	19024	17957	32605	30889	22546	25816	20752	24359
Weaning (300-600 µm) Kg compound diet Min	98770	83510	79265	74820	135854	128704	93942	107568	86466	101495
Weaning (300-600 µm) Kg compound diet Max	138278	116914	110971	104748	190195	180185	131519	150595	121053	142093
Nursery (0,5-1,1mm or 0,3-3gr fish) Kg compound diet Min	794111	671420	637291	601553	1092262	1034779	755294	864847	695189	816019
Nursery (0,5-1,1mm or 0,3-3gr fish) Kg compound diet Max	825717	698144	662655	625495	1135735	1075964	785356	899268	722858	848497
Broodstock feeds Min Kg compound diet	31606	26723	25365	23942	43473	41185	30061	34422	27669	32478
Broodstock feeds Max Kg compound diet	47410	40085	38047	35914	65210	61778	45092	51633	41504	48718

Table 43 – Total quantity (global) of diets for European seabass (juveniles) (2014-2023)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Rotifers Min	8341	7608	7765	8451	12273	12939	11835	12796	11854	12780
Rotifers Max	13902	12681	12941	14086	20455	21565	19726	21327	19757	21300
Enrichment Rotifers Min	4866	4438	4529	4930	7159	7548	6904	7465	6915	7455
Enrichment Rotifers Max	13902	12681	12941	14086	20455	21565	19726	21327	19757	21300
Artemia small -not enriched (Min)	6951	6340	6471	7043	10228	10782	9863	10664	9879	10650
Artemia small -not enriched (Max)	12511	11413	11647	12677	18410	19408	17753	19195	17782	19170
Artemia large enriched (Min)	83410	76085	77647	84514	122732	129388	118354	127965	118544	127798
Artemia large enriched (Max)	90360	82425	84118	91556	132960	140170	128217	138628	128422	138447
Enrichment Artemia products (Min)	25023	22825	23294	25354	36820	38816	35506	38389	35563	38339
Enrichment Artemia products (Max)	36144	32970	33647	36623	53184	56068	51287	55451	51369	55379
Co-feeding (200-300 µm) Min	27803	25362	25882	28171	40911	43129	39451	42655	39515	42599
Co-feeding (200-300 µm) Max	41705	38042	38824	42257	61366	64694	59177	63982	59272	63899
Weaning (300-600 µm) Min	173770	158510	161765	176070	255692	269558	246572	266593	246966	266245
Weaning (300-600 µm) Max	243278	221914	226471	246498	357968	377382	345201	373230	345753	372743
Nursery (0,5-1,1mm or 0,3-3gr fish) Min	1397111	1274420	1300591	1415603	2055760	2167249	1982438	2143408	1985609	2140609
Nursery (0,5-1,1mm or 0,3-3gr fish) Max	1452717	1325144	1352355	1471945	2137581	2253508	2061341	2228717	2064638	2225807
Broodstock feeds Min	55606	50723	51765	56342	81821	86259	78903	85310	79029	85198
Broodstock feeds Max	83410	76085	77647	84514	122732	129388	118354	127965	118544	127798

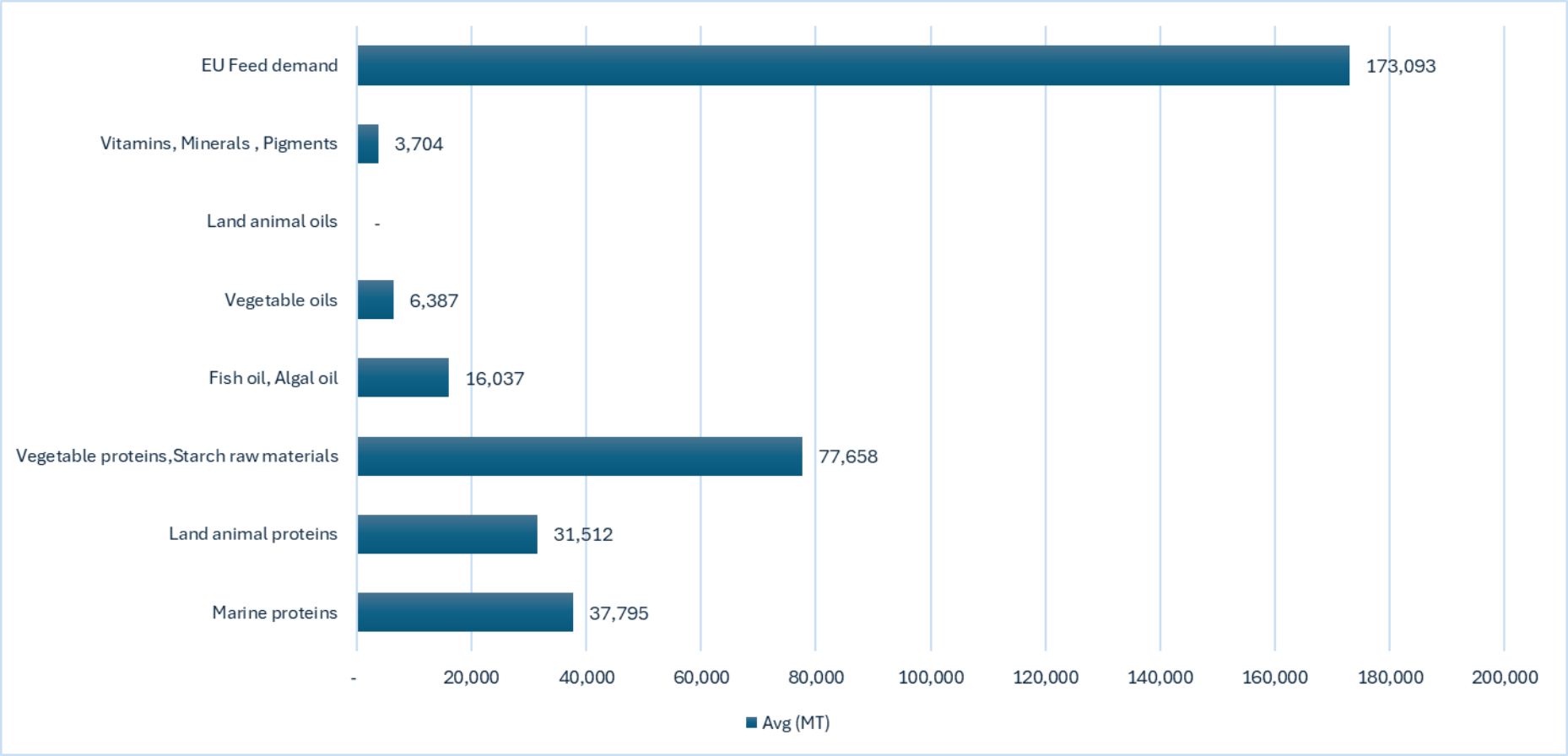
Table 44 – Feed demand (tonnes) of feed for European seabass (adults)

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Croatia	5,652	6,429	8,977	10,620	11,232	12,440	12,178	13,508	18,167	20,069	17,030
Cyprus	2,844	3,634	3,452	3,034	4,508	4,778	5,672	5,848	5,360	3,918	3,708
France	4,856	4,489	4,312	3,500	2,800	3,443	4,921	4,752	2,501	2,160	1,932
Greece	69,839	64,283	73,200	84,959	88,569	93,822	82,474	81,526	102,464	94,291	88,402
Italy	12,660	11,449	11,600	13,600	13,600	11,476	14,840	12,306	14,554	9,944	9,638
Malta	254	380	54	78	119	154	124	271	442	278	31
Portugal	1,151	909	591	807	1,401	399	1,349	1,809	1,667	2,962	3,407
Slovenia	100	132	140	140	160	160	160	100	75	97	120
Spain	29,891	33,445	37,201	45,912	35,312	42,538	50,520	45,530	46,075	48,242	48,827
Total Fish Feed	127,247	125,150	139,527	162,649	157,701	169,210	172,239	165,650	191,304	181,961	173,093
Global Fish Feed	294,404	311,848	326,878	382,680	431,144	462,046	519,752	547,017	586,461	576,347	573,935

9.4.3.1. Diet composition and material demand

One of the feed producers (Irida, 2023) used in the calculation of the average combines all plant products (vegetable proteins and starch raw materials) as one category. The other producer used (Skretting, 2023) separates them (see data in Annex 1). To find an average for these categories - the Skretting values of vegetable proteins and starch raw materials were combined). This applies to all species fed Irida diets - seabass, seabream, meagre and sole.

Figure 57 – Estimated EU material demand for European seabass (tonnes) (2023)



9.5. Gilthead seabream

9.5.1. Life history

Sparus aurata is commonly found in the Mediterranean Sea and along the Eastern Atlantic coast from Great Britain to Senegal, though it is rare in the Black Sea. This species inhabits both brackish and marine waters due to its euryhaline and eurythermal nature (Pavlidis & Mylonas, 2011). Spawning typically occurs from December to April, when water temperatures range from 13–17°C (Cataudella, 1995). Juveniles usually migrate towards coastal waters with milder temperatures and abundant trophic resources in early spring. Subsequently, at the beginning of Autumn, they return to the open sea where adult fish breed (FAO, 2009b).

Gilthead seabreams are typically found in rocky and seagrass (*Posidonia oceanica*) meadows as well as sandy grounds. Young fish inhabit relatively shallow areas (up to 30 m), whereas adults can reach deeper waters, generally not exceeding 50 m. This species is a protandrous hermaphrodite, with females reaching sexual maturity at 2-3 years and males at 2 years of age (Basurco *et al* 2011). The gilthead seabream adjusts its feeding habits based on the availability of resources, as it is an opportunistic feeder (Pita *et al* 2002). Its diet primarily consists of bivalves and gastropods as well as polychaetes, echinoderms and teleosts. The occasional consumption of ascidians, algae and bryozoans further indicates an omnivorous feeding strategy (Wassef and Eisawy, 1985).

Traditionally, gilthead seabream was cultured extensively in coastal lagoons and saltwater ponds using fish systems that functioned like natural fish traps and utilising the natural trophic migration of juveniles from the sea to these lagoons. This practise continued until intensive rearing systems were developed during the 1980s. Artificial breeding was successfully achieved in Italy in 1981-82 and large-scale production of gilthead seabream juveniles was definitively achieved in Spain, Italy and Greece in 1988-1989. The hatchery production and farming of this fish is considered one of the success stories in the aquaculture industry (FAO, 2009b).

In land-based hatcheries, seabream eggs are produced from selected broodstock of various age groups, ranging from 1-year-old males to 10-year-old females. The broodstock are typically kept in tanks (10–20 m^3) at a density of 4–8 kg m^{-1}. In order to ensure a good fertilization rate, as females are batch spawners capable of laying approximately 20,000–30,000 egg kg^{-3} for a period of 3–4 months, the male to female ratio is generally maintained at 3:1 (Calderer & Cardona, 1993).

9.5.2. Production trends and statistics

Numerous studies investigated the effects of various factors, including the age of female broodstock and dietary n-3 HUFA levels, on spawning. Notably, mature female gilthead seabream at 3 years of age demonstrated higher fertility and comparable equal egg quality parameters to older females aged 4–6 years. Additionally, a dietary intake of 1.6% n−3 HUFA improved spawning quality in terms of fecundity, hatching rates and larval survival (Fernández-Palacios *et al* 1995).

Gilthead sea bream is mainly farmed intensively in sea cages at average densities of 15–25 kg m^{-3} with a feed conversion ratio (FCR) of around 2. The culture period varies based on location and water temperature, but usually it takes between 18 and 24 months for a specimen to reach 400 g from hatched larvae (Basurco *et al* 2011).

In 2013, EU Countries produced 93,000 tonnes of gilthead seabream, accounting for up to 60% of the global market share. However, over the next ten years, overall production only increased by 14%, reaching 106,000 tonnes in 2023. This resulted in a loss of market share, with the EU now representing merely 30% of global production

As of 2023, Greece is the largest gilthead seabream producer with approximately 65,500 tonnes followed by Spain and Croatia with 13,000 and 9,000 tonnes respectively Globally, Türkiye has emerged as the main contributor to market growth for this species over the past decade, significantly expanding its seabream farming capabilities from 35,000 tonnes in 2013 to 154,000 tonnes in 2023.

Figure 58 – Gilthead seabream production volumes (tonnes) over a ten-year period

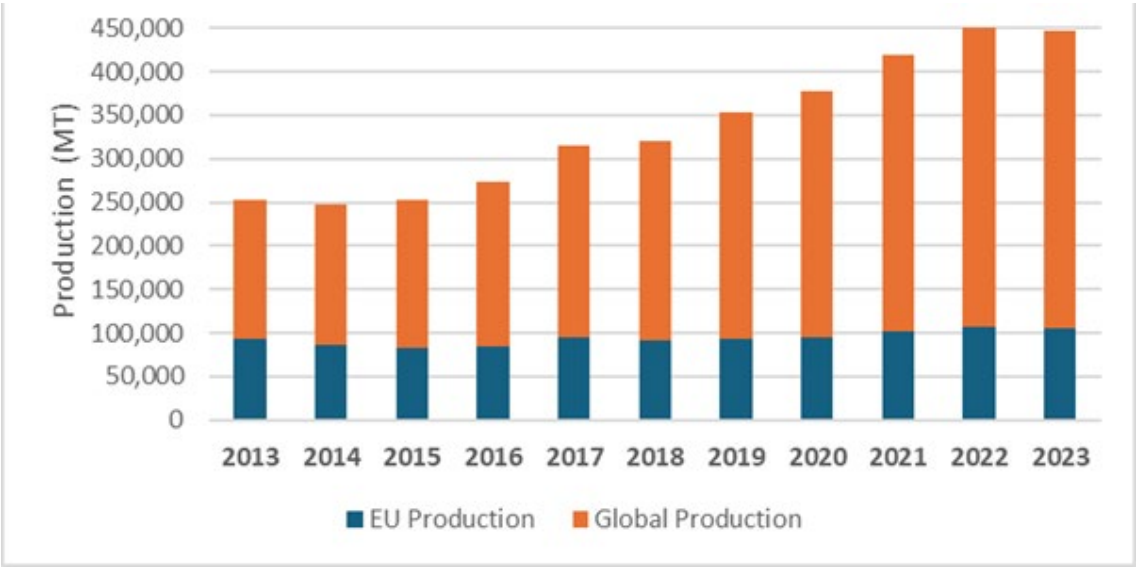


Figure 59 – Top EU gilthead seabream producing countries in 2023

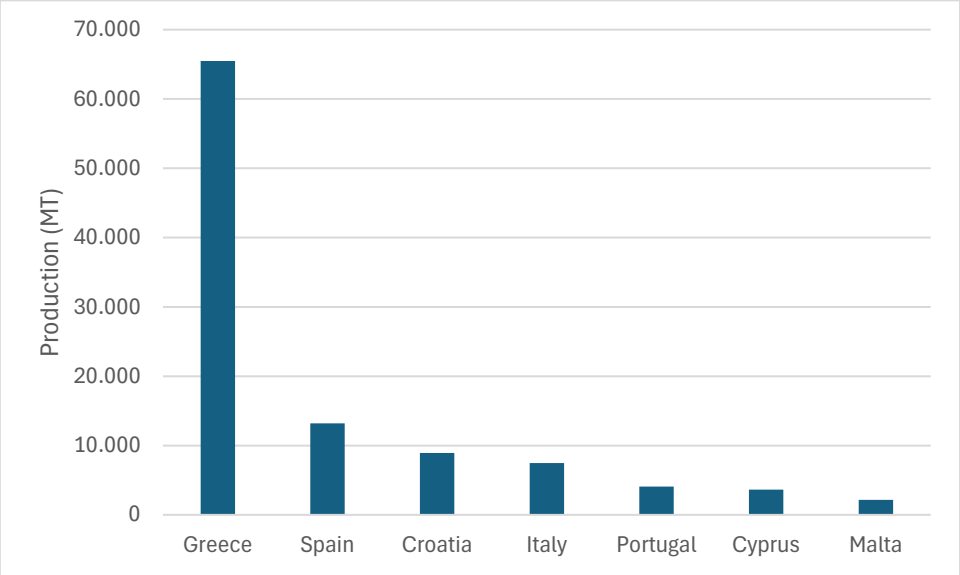


Figure 60 – Top gilthead seabream producing countries globally in 2023

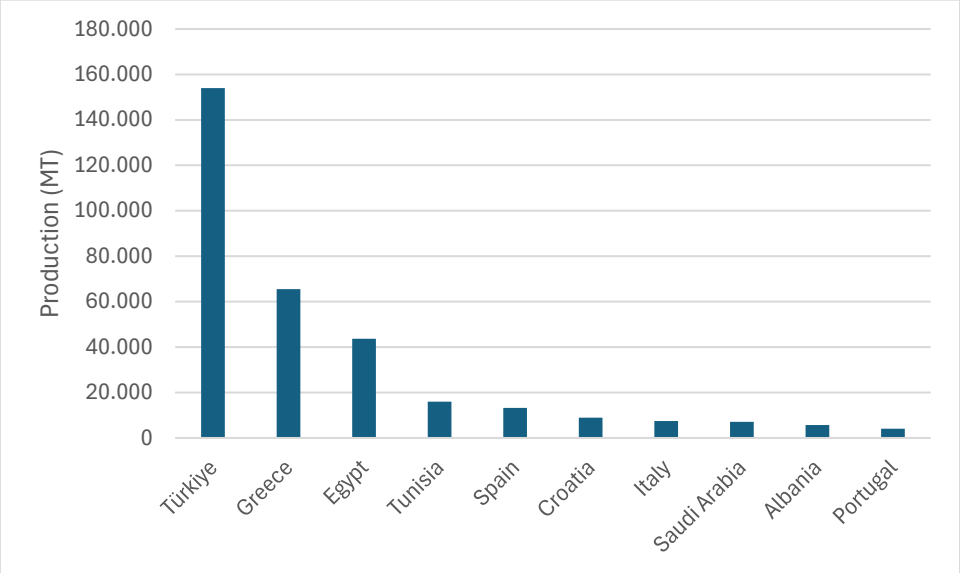


Figure 61 – Gilthead seabream global production value and average fish price per kilo over a ten-year period

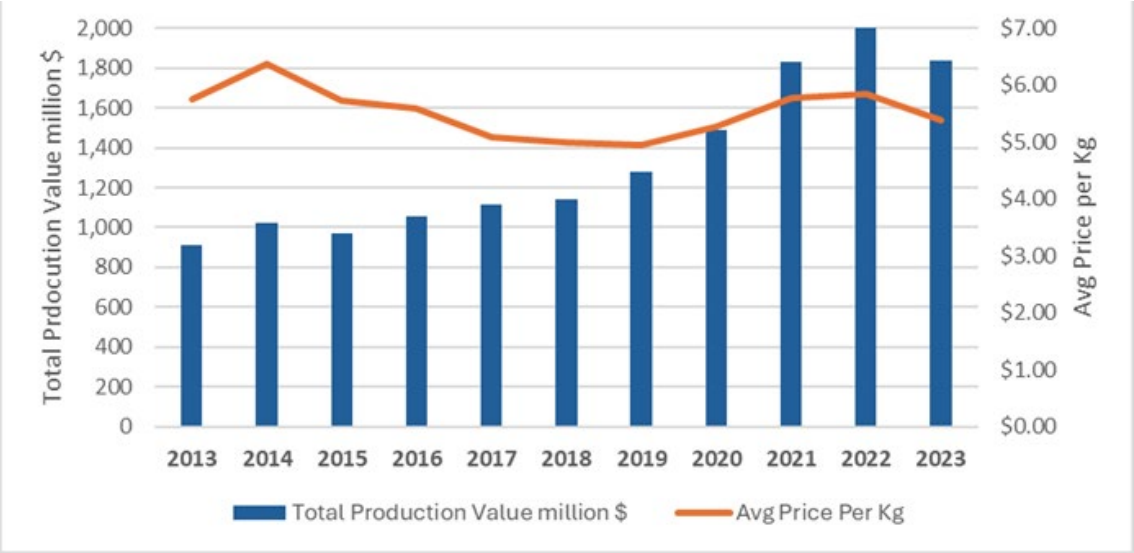


Table 45 – Total production (tonnes) of gilthead seabream 2013-2023

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Croatia	2,978	3,655	4,075	4,101	4,830	5,591	6,774	7,780	7,599	7,506	8,922
Cyprus	3,795	2,919	4,045	5,039	4,949	4,885	5,168	4,367	5,097	5,496	3,651
France	1,636	1,379	1,381	1,500	1,500	1,608	2,344	2,006	491	393	902
Greece	55,751	50,688	47,713	49,621	55,948	56,203	55,452	61,976	66,891	70,315	65,474
Italy	6,184	6,830	6,800	7,600	7,600	7,316	7,350	7,718	8,176	7,928	7,478
Malta	2,550	2,704	2,337	2,221	2,458	1,779	1,783	2,598	2,640	2,096	2,165
Portugal	1,427	1,602	1,099	1,162	1,038	898	2,316	1,768	3,091	3,352	4,081
Slovenia	0	0	0	0	0	0	0	0	43	38	45
Spain	18,897	16,915	16,005	12,397	17,005	13,810	12,475	6,458	7,823	9,038	13,206
Total EU Species Production	93,218	86,693	83,455	83,641	95,328	92,091	93,663	94,670	101,851	106,160	105,924
Global Species Production	158,875	160,735	169,185	189,263	219,305	228,673	259,454	283,510	317,962	343,717	341,289

9.5.3. FCR and feed costs calculation

Feed demand was estimated by considering the average FCR of seabream for the whole production cycle. Abdou *et al* (2017) after 18 months of feeding from 4 g fry to 400 g adults found an FCR of 1.85. Garcia *et al* (2016) with a similar feeding cycle of 18 months observed and overall FCR of 2. Additionally, Kallitsis *et al* (2020) in trial with an initial starting weight of 2 g and a final weight of 600g detected and FCR of 2.5. Also, from personal communication with various aquaculture units the average FCR is estimated to be around 2.

The Hellenic Aquaculture Producers Organisation (HAPO, 2024) provide average food prices per year, which were used in the calculation of estimated value of feed.

9.5.4. Diet composition

Table 46 – Indicative diet composition of gilthead seabream

Raw Material Category	Larvae Materials	Juvenile - Grower Materials
Vegetable protein sources	Maze gluten, Wheat gluten and Soy protein Concentrate	Soya meal, Sunflower cake/expeller, Maze gluten, Soy protein concentrate, Rapeseed meal, Lupin meal and Faba beans
Vegetable oils	Refined palm oil	Rapeseed oil, Soybean oil and Camelina oil
Carbohydrate sources	Wheat starch, Wheat Flour	Wheat Flour, Dry Distillers Grains with Solubles (DDGs)
Marine protein sources	Fish meal, Krill meal, Squid meal and Hydrolysed fish protein	Fish meal, Krill meal, Squid meal and Hydrolysed fish protein
Land protein sources	Blood meal and Whey protein	Blood meal, Hydrolysed feather meal, Poultry meal, Haemoglobin powder and Whey protein
Land oil sources	-	Poultry oil
Single cell proteins	Dried algae (*Haematococcus pluvialis, Schizochytrium limacinum*), brewers yeast (*Saccharomyces cerevisiae*).	Dried algae (*Haematococcus pluvialis, Schizochytrium limacinum*), brewers yeast
Marine oils	Fish oil and Algal oil	Fish oil and Algal oil
Micro materials (Antioxidants, Preservatives , Additives, Minerals, Vitamins, Probiotics)	Antioxidants (BHA, BHT, Propyl gallate and Citric acid)	Antioxidants (BHA, BHT, Propyl gallate and Citric acid)
	Preservatives (Sorbic acid, Calcium propionate, Orthophosphoric acid and Sodium Propionate)	Preservatives (Sorbic acid, Calcium propionate, Orthophosphoric acid)

Raw Material Category	Larvae Materials	Juvenile - Grower Materials
	Additives (Herb extracts, Fish gelatin, Lecithin, Phospholipids)	Additives (Herb extracts, Fish gelatin, Betaine, Lecithin, Phospholipids)
	Vitamins (A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, Choline chloride)	Vitamins (A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, Choline chloride, Inositol)
	Minerals (Phosphorus, Calcium, Iron, Iodine, Copper, Manganese, Selenium and Zinc)	Minerals (Phosphorus, Calcium, Iron, Iodine, Copper, Manganese, Selenium and Zinc)
	Amino acids (Methionine)	Amino acids (Lysine, Methionine and Threonine)
	Probiotics (*Pediococcus acidilactici*)	Probiotics (*Pediococcus acidilactici*)

Table 47 – Gilthead seabream (Juvenile) feed demand (EU) (2014-2023)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Rotifers Min (billion)	10,049	8,789	9,982	10,096	9,963	8,391	8,004	8,428	8,152	8,695
Rotifers Max (billion)	14,424	14,039	15,982	16,471	18,014	18,863	19,527	22,443	24,152	24,870
Enrichment Rotifers Min (L)	6,030	5,274	5,989	6,057	5,978	5,035	4,802	5,057	4,891	5,217
Enrichment Rotifers Max (L)	12,059	10,547	11,978	12,115	11,955	10,069	9,604	10,113	9,782	10,434
Artemia small (kg cysts) -not enriched (Min)	2,010	1,758	1,996	2,019	1,993	1,678	1,601	1,686	1,630	1,739
Artemia small (kg cysts) -not enriched (Max)	2,814	2,461	2,795	2,827	2,790	2,350	2,241	2,360	2,282	2,435
Artemia large enriched (kg cysts) (Min)	40,197	35,157	39,928	40,382	39,850	33,565	32,014	33,711	32,607	34,781
Artemia large enriched (kg cysts) (Max)	44,217	38,673	43,921	44,420	43,835	36,921	35,216	37,082	35,868	38,259
Enrichment Artemia products (L)(Min)	12,059	10,547	11,978	12,115	11,955	10,069	9,604	10,113	9,782	10,434
Enrichment Artemia products (L) (Max)	17,687	15,469	17,568	17,768	17,534	14,768	14,086	14,833	14,347	15,304
Co-feeding (200-300 µm) kg compound diet Min	16,079	14,063	15,971	16,153	15,940	13,426	12,806	13,484	13,043	13,912
Co-feeding (200-300 µm) kg compound diet Max	24,118	21,094	23,957	24,229	23,910	20,139	19,208	20,227	19,564	20,869
Weaning (300-600 µm) kg compound diet Min	100,493	87,893	99,820	100,955	99,626	83,912	80,035	84,278	81,517	86,953

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Weaning (300-600 µm) kg compound diet Max	140,690	123,050	139,748	141,337	139,476	117,476	112,049	117,989	114,124	121,734
Nursery (0.5-1.1 mm or 0.3-3 g fish) kg compound diet Min	807,960	706,656	802,553	811,678	800,991	674,649	643,483	677,591	655,399	699,100
Nursery (0.5-1.1mm or 0.3-3 g fish) kg compound diet Max	840,117	734,781	834,495	843,984	832,871	701,501	669,095	704,560	681,484	726,925
Broodstock feeds Min kg compound diet	32,158	28,126	31,942	32,306	31,880	26,852	25,611	26,969	26,086	27,825
Broodstock feeds Max kg compound diet	48,236	42,188	47,914	48,458	47,820	40,278	38,417	40,453	39,128	41,737

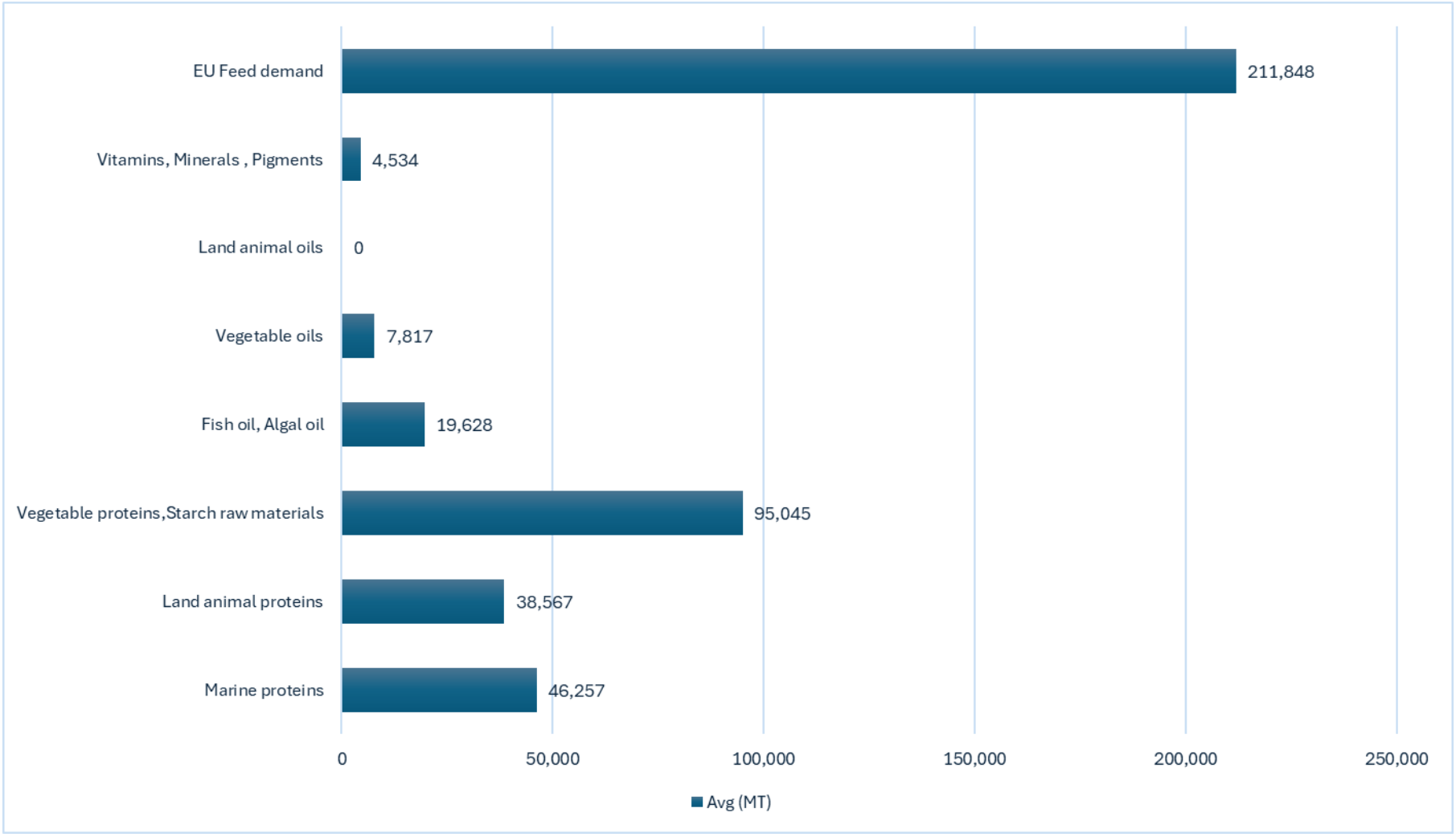
Table 48 – Gilthead seabream (juvenile) feed demand (Global) (2014-2023)

	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Rotifers Min (billion)	14,424	14,039	15,982	16,471	18,014	18,863	19,527	22,443	24,152	24,870
Rotifers Max (billion)	17,309	16,847	19,178	19,765	21,617	22,635	23,433	26,931	28,982	29,844
Enrichment Rotifers Min (L)	8,655	8,424	9,589	9,882	10,808	11,318	11,716	13,466	14,491	14,922
Enrichment Rotifers Max (L)	17,309	16,847	19,178	19,765	21,617	22,635	23,433	26,931	28,982	29,844
Artemia small (Kg cysts) -not enriched (Min)	2,885	2,808	3,196	3,294	3,603	3,773	3,905	4,489	4,830	4,974
Artemia small (Kg cysts) -not enriched (Max)	4,039	3,931	4,475	4,612	5,044	5,282	5,468	6,284	6,762	6,964
Artemia large enriched (kg cysts) (Min)	57,697	56,157	63,928	65,882	72,056	75,451	78,109	89,771	96,607	99,481
Artemia large enriched (kg cysts) (Max)	63,467	61,773	70,321	72,470	79,261	82,996	85,920	98,748	106,268	109,429
Enrichment Artemia products (L)(Min)	17,309	16,847	19,178	19,765	21,617	22,635	23,433	26,931	28,982	29,844
Enrichment Artemia products (L) (Max)	25,387	24,709	28,128	28,988	31,705	33,199	34,368	39,499	42,507	43,772
Co-feeding (200-300 µm) kg compound diet Min	23,079	22,463	25,571	26,353	28,822	30,181	31,243	35,908	38,643	39,792
Co-feeding (200-300 µm) kg compound diet Max	34,618	33,694	38,357	39,529	43,234	45,271	46,865	53,863	57,964	59,689
Weaning (300-600 µm) kg compound diet Min	144,243	140,393	159,820	164,705	180,140	188,628	195,272	224,428	241,517	248,703
Weaning (300-600 µm) kg compound diet Max	201,940	196,550	223,748	230,587	252,196	264,079	273,380	314,199	338,124	348,184
Nursery (0.5-1.1 mm or 0.3-3 g fish) kg compound diet Min	1,159,710	1,128,756	1,284,953	1,324,228	1,448,324	1,516,570	1,569,985	1,804,397	1,941,799	1,999,570
Nursery (0.5-1.1 mm or 0.3-3 g fish) kg compound diet Max	1,205,867	1,173,681	1,336,095	1,376,934	1,505,968	1,576,931	1,632,472	1,876,214	2,019,084	2,079,155
Broodstock feeds Min kg compound diet	3,858,912	3,375,072	3,833,088	3,876,672	3,825,629	3,222,206	3,073,354	3,236,256	3,130,262	3,338,985
Broodstock feeds Max Kg compound diet	5,788,368	5,062,608	5,749,632	5,815,008	5,738,443	4,833,310	4,610,030	4,854,384	4,695,394	5,008,477

Table 49 – EU and Global production, and feed demand of Gilthead seabream (2013-2023)

Country (Name)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Croatia	5,956	7,309	8,150	8,202	9,659	11,182	13,549	15,560	15,199	15,011	17,845
Cyprus	7,590	5,838	8,090	10,078	9,898	9,770	10,336	8,734	10,194	10,992	7,302
France	3,272	2,758	2,762	3,000	3,000	3,216	4,689	4,013	982	785	1,804
Greece	111,503	101,376	95,427	99,242	111,895	112,406	110,904	123,951	133,782	140,630	130,948
Italy	12,368	13,661	13,600	15,200	15,200	14,633	14,700	15,435	16,352	15,855	14,956
Malta	5,100	5,408	4,674	4,442	4,916	3,558	3,566	5,196	5,281	4,192	4,329
Portugal	2,854	3,204	2,198	2,325	2,076	1,796	4,632	3,536	6,181	6,704	8,162
Slovenia	0	0	0	0	0	0	0	0	86	75	90
Total EU Species Feed Demand	186,437	173,386	166,911	167,282	190,656	184,182	187,326	189,341	203,702	212,321	211,848
Global Species Feed Demand	317,750	321,470	338,370	378,527	438,609	457,345	518,908	567,021	635,924	687,435	682,577

Figure 62 – Estimated EU feed material demand for gilthead seabream (tonnes) (2023)



9.6. Meagre

9.6.1. Life history

The meagre (*Argyrosomus regius*), a member of the Sciaenidae family, is a carnivorous species native to the Mediterranean Sea, the Black Sea and the Eastern Atlantic Ocean from Norway to Congo. It typically inhabits coastal waters but can be found at depths ranging from 15 to 200 metres. The species has many marketable qualities and characteristics which make it suitable for aquaculture.

Meagre is euryhaline and can tolerate a wide range of salinities, making it adaptable to both brackish and marine environments. It is known for its fast growth rate (~1 kg/year), and good resistance to stress, which are desirable traits for intensive aquaculture systems (FAO, 2010b; Campoverde Vera, 2018).

The optimal temperature range for growth is generally considered to be between 17°C and 21°C, (FAO, 2025a). Spawning is believed to occur most effectively at temperatures between 17°C and 22°C, while larval feeding is observed around 20°C to 21°C. Feeding activity in meagre declines significantly when water temperatures drop below 13°C to 15°C during winter months (Estévez *et al* 2011). Observations of broodstock indicate a complete cessation of feeding below 14°C and above 25°C (Duncan *et al* 2013). Despite the importance of temperature, most growth optimization research has focused on dietary formulations, often neglecting the role of thermal conditions.

Spawning in captivity has been achieved, with peak spawning occurring when water temperatures rise in spring and summer. Broodstock management in land-based hatcheries typically involves temperature and photoperiod manipulation to induce spawning. Females are batch spawners, capable of producing high-quality eggs under controlled conditions.

Meagre juveniles are often found in estuaries and shallow coastal lagoons, while adults prefer deeper open sea waters. The species migrates seasonally, often approaching coastal areas in spring and retreating to deeper waters in winter. This natural behaviour has been exploited in traditional fisheries and increasingly in aquaculture practices. The species demonstrates cannibalistic behaviour during the post-flexion larval stage, making size grading and optimized feeding strategies critical during weaning and early juvenile phases.

Meagre is an opportunistic carnivore. In the wild, it feeds on crustaceans, cephalopods and small fish. In captivity, larvae are initially fed rotifers and *Artemia*, followed by weaning onto formulated diets. Nutritional studies highlight the species-specific requirement for docosahexaenoic acid (DHA), with poor elongation and desaturation capacity from precursors like 18:3n-3 and 18:4n-3. Enrichment of live feed with high DHA emulsions significantly improves larval survival, growth, and fatty acid profiles.

9.6.2. Production trends and statistics

Commercial production of Meagre began in the late 1990s in France and Italy and expanded to Spain, Greece, Turkey and Egypt by the mid-2000s. Meagre farming has seen rapid growth, reaching over 50,000 tonnes in 2023 from virtually zero in 2000. Production is mainly conducted in sea cages and ponds, with increasing interest in land-based RAS systems. The species is farmed at densities similar to seabass and seabream and juveniles accept commercial feeds developed for other marine species. However, meagre-specific feeds are recommended for optimal growth and health.

Despite being relatively unknown to the across most of Europe, meagre is highly valued in Mediterranean markets for its taste and texture. The fish is primarily sold whole but has strong potential for portioned fillet markets due to its size and body conformation. Early market development has focused on premium segments, but increasing production is expected to shift it toward more mainstream markets.

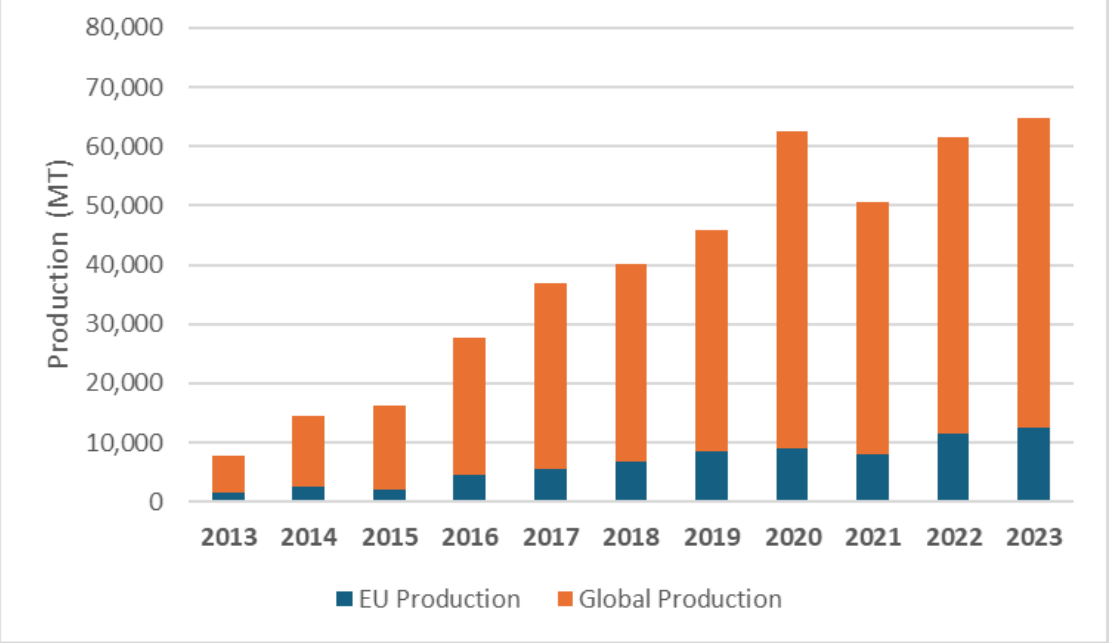
As of the 2010 FAO report, production costs remain relatively high due to the use of live feeds and specialized rearing practices. However, ongoing R&D efforts aim to reduce costs and increase production efficiency, making meagre a viable candidate for further aquaculture expansion.

In 2013, EU Countries accounted for up to 24% of the global market share which they have maintained over a ten-year period, by steadily increasing overall production each year, following competitively the rest of the world with an almost 10-fold increase from 1,400 tonnes in 2013 to 12,500 tonnes in 2023.

As of 2023, Spain is the largest producer, with approximately 7,600 tonnes, followed by Greece, Italy and Cyprus with 4,449, 355 and 107 tonnes respectively. Egypt is the main contributor to the market growth for this species over the past decade, significantly expanding its farming capabilities from 4,900 tonnes in 2013 to 33,000 tonnes in 2023.

The overall value of meagre had a 6-fold increase from approximately USD 28 million in 2013 to USD 180 million in 2023. This growth is largely attributed to increased production, as prices, while fluctuating, have not significantly risen.

Figure 63 – Production volumes of meagre (tonnes) over a ten-year period



Source: FishStatJ (FAO 2025c) (EU production is calculated as production from Croatia, Cyprus, France, Greece, Italy, Portugal, and Spain).

Figure 64 – Top EU meagre producing countries in 2023

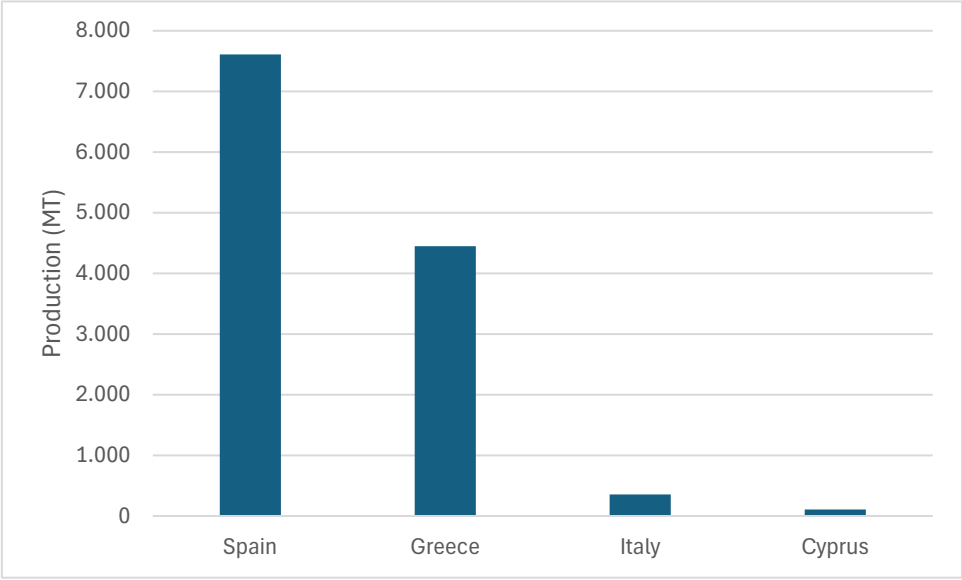


Figure 65 – Top meagre producing countries globally in 2023

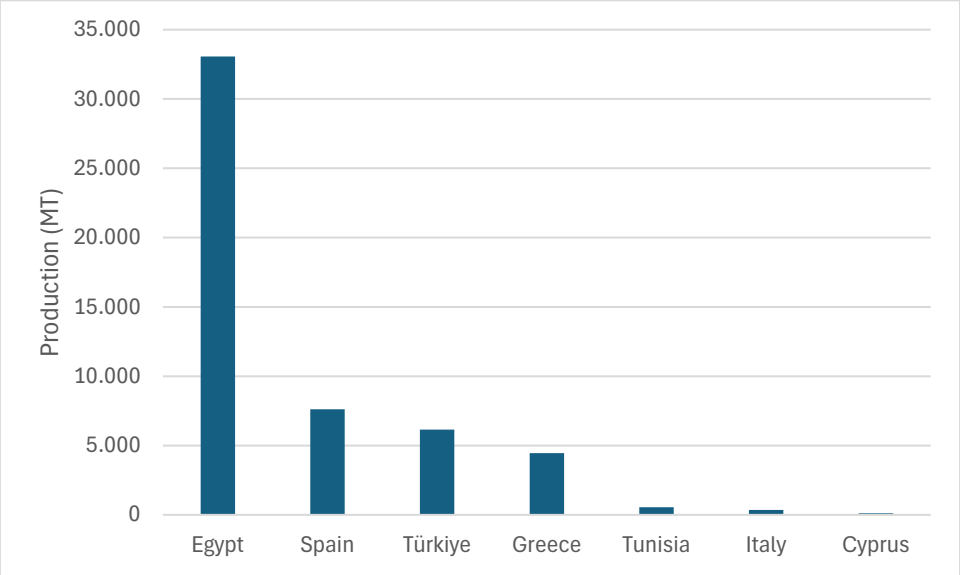


Figure 66 – Meagre global production value and average fish price per kilo over a ten-year period.

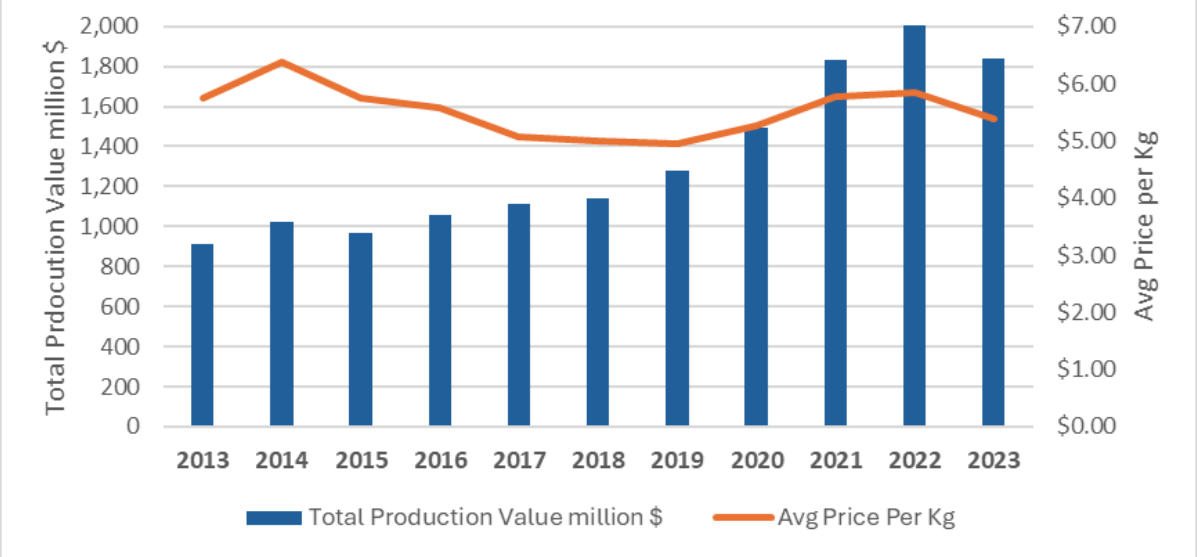


Table 50 – Production of meagre (tonnes) 2013-2023

Country (Name)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Croatia	44	60	67	125	253	808	725	618	999	1,086	0
Cyprus	49	33	14	3	0	1	0	0	13	58	107
France	446	588	600	256	0	251	669	501	0	0	0
Greece	376	795	5	2,204	1,634	1,639	2,415	3,427	4,201	5,697	4,449
Italy	38	28	30	100	100	75	75	106	123	246	355
Portugal	5	4	61	63	70	33	7	0	0	0	0
Spain	483	1,101	1,301	1,707	3,524	3,929	4,535	4,415	2,788	4,525	7,611
Total Species Production	1,441	2,609	2,078	4,459	5,581	6,736	8,426	9,066	8,124	11,612	12,522
Global Species Production	6,330	11,797	14,198	23,124	31,336	33,512	37,504	53,394	42,558	49,847	52,280

Table 51 – EU and Global feed demand of meagre (2013-2023

Country (Name)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Croatia	87	120	133	251	507	1,616	1,449	1,236	1,998	2,171	0
Cyprus	97	66	28	6	0	2	0	0	26	116	214
France	893	1,176	1,200	512	0	503	1,339	1,002	0	0	0
Greece	752	1,590	10	4,408	3,268	3,278	4,830	6,853	8,401	11,394	8,898
Italy	76	57	60	200	200	151	150	211	246	492	710
Portugal	10	7	122	127	140	65	14	0	0	0	0

Country (Name)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Spain	966	2,203	2,602	3,415	7,047	7,858	9,070	8,829	5,577	9,050	15,222
Total Species Feed Demand	2,882	5,219	4,156	8,918	11,162	13,473	16,851	18,132	16,248	23,223	25,045
Global Species Feed Demand	12,660	23,594	28,396	46,248	62,672	67,025	75,007	106,788	85,115	99,693	104,560

9.6.3. FCR and feed costs calculation

Feed demand was estimated by taking into account the average FCR of meagre for the entire production cycle. Existing growth trials involving juvenile and market-size meagre have been conducted at water temperatures ranging from 8.5°C to 26.5°C. These studies encompassed a wide range of fish sizes, including 15.2g–393 g (Chatzifotis *et al* 2010; Estévez *et al*., 2011; Martínez-Llorens *et al* 2011; Chatzifotis *et al,* 2012; Fernandes, 2013; Velazco Vargas *et al* 2013; García-Mesa *et al* 2014; Emre *et al* 2016; Güroy *et al* 2017; Magnoni *et al,* 2017), 12.8–831 g (Piccolo *et al* 2008), and 356g–1138 g (Fountoulaki *et al* 2017). Across these trials, the reported average and median water temperatures were approximately 20.5°C and 21°C, respectively. Specific growth rates (SGR) and FCR varied widely, with SGR ranging from 0.30% to 1.43% and FCR values between 0.76 and 3.20. For the purposes of this study, by combining the information provided by these authors and personal communication with various aquaculture units, we assume average FCR = 2. The value of juvenile FCR (1.63) was taken from the average values of Chatzifotis *et al* (2010) (1.49) and Abdel-Rahim (2020) (1.77).

The Hellenic Aquaculture Producers Organisation (HAPO, 2024) provide average food prices per year, which were used in the calculation of estimated value of feed.

9.6.4. Diet composition

Table 52 – Indicative diet composition of meagre

Raw Material Category	Larvae Materials	Juvenile - Grower Materials
Vegetable protein sources	Maze gluten, Wheat gluten and Soy protein Concentrate	Soya meal, Sunflower cake/expeller, Maze gluten, Soy protein concentrate, Rapeseed meal, Lupin meal and Faba beans
Vegetable oils	Refined palm oil	Rapeseed oil, Soybean oil and Camelina oil
Carbohydrate sources	Wheat starch, Wheat Flour	Wheat Flour, Dry Distillers Grains with Solubles (DDGs)
Marine protein sources	Fish meal, Krill meal, Squid meal and Hydrolyzed fish protein	Fish meal, Krill meal, Squid meal and Hydrolyzed fish protein
Land protein sources	Blood meal and Whey protein	Blood meal, Hydrolyzed feather meal, Poultry meal, Hemoglobin powder and Whey protein
Land oil sources	-	Poultry oil

Raw Material Category	Larvae Materials	Juvenile - Grower Materials
Single cell proteins	Dried algae (*Haematococcus pluvialis, Schizochytrium limacinum*), brewers yeast (*Saccharomyces cerevisiae*).	Dried algae (*Haematococcus pluvialis, Schizochytrium limacinum*), brewers yeast
Marine oils	Fish oil and Algal oil	Fish oil and Algal oil
Micro materials (Antioxidants, Preservatives , Additives, Minerals, Vitamins, Probiotics)	Antioxidants (BHA, BHT, Propyl gallate and Citric acid)	Antioxidants (BHA, BHT, Propyl gallate and Citric acid)
	Preservatives (Sorbic acid, Calcium propionate, Orthophosphoric acid and Sodium Propionate)	Preservatives (Sorbic acid, Calcium propionate, Orthophosphoric acid)
	Additives (Herb extracts, Fish gelatin, Lecithin, Phospholipids)	Additives (Herb extracts, Fish gelatin, Betaine, Lecithin, Phospholipids)
	Vitamins (A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, Choline chloride)	Vitamins (A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, Choline chloride, Inositol)
	Minerals (Phosphorus, Calcium, Iron, Iodine, Copper, Manganese, Selenium and Zinc)	Minerals (Phosphorus, Calcium, Iron, Iodine, Copper, Manganese, Selenium and Zinc)
	Amino acids (Methionine)	Amino acids (Lysine, Methionine and Threonine)
	Probiotics (*Pediococcus acidilactici*)	Probiotics (*Pediococcus acidilactici*)

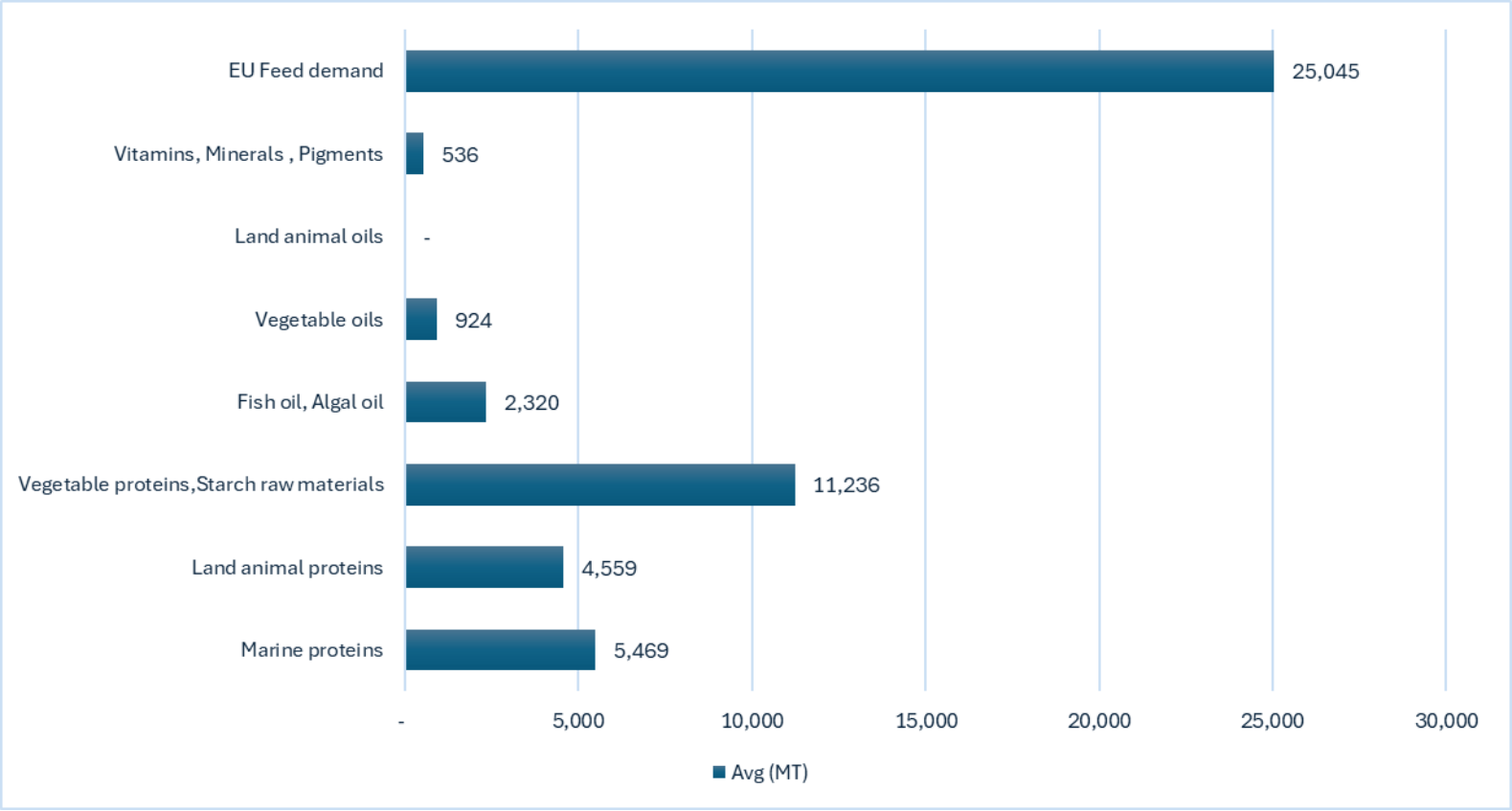
Table 53 – Quantity of juvenile feeds (meagre) 2021-2023 (EU)

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Rotifers Min (billion)	49	63	62	103	167	160	130	147	9	8
Rotifers Max (billion)	329	293	262	163	291	444	754	643	409	528
Enrichment Rotifers Min (L)	30	38	37	62	100	96	78	88	6	5
Enrichment Rotifers Max (L)	62	79	77	129	208	200	163	184	12	10
Artemia small (Kg cysts) -not enriched (Min)	20	25	25	41	67	64	52	59	4	3
Artemia small (Kg cysts) -not enriched (Max)	37	47	46	77	125	120	98	110	7	6
Artemia large enriched (kg cysts) (Min)	284	362	354	592	958	922	748	845	53	45
Artemia large enriched (kg cysts) (Max)	351	447	437	731	1183	1138	924	1043	65	55
Enrichment Artemia products (L)(Min)	85	109	106	178	287	276	224	253	16	13
Enrichment Artemia products (L) (Max)	140	179	175	293	473	455	369	417	26	22
Co-feeding (200-300 µm) Kg compound diet Min	99	126	123	206	333	321	260	294	18	16
Co-feeding (200-300 µm) Kg compound diet Max	148	189	185	309	500	481	390	441	28	23
Weaning (300-600 µm)Kg compound diet Min	618	788	770	1288	2083	2004	1626	1836	115	98
Weaning (300-600 µm)Kg compound diet Max	865	1103	1078	1803	2916	2805	2277	2570	161	137
Nursery (0,5-1,1mm or 0,3-3gr fish) Kg compound diet Min	4965	6332	6191	10352	16743	16109	13075	14761	925	784
Nursery (0,5-1,1mm or 0,3-3gr fish)Kg compound diet Max	5162	6584	6437	10764	17410	16750	13595	15349	961	815
Broodstock feeds Min Kg compound diet	222	284	277	464	750	721	585	661	41	35
Broodstock feeds Max Kg compound diet	321	410	400	670	1083	1042	846	955	60	51

Table 54 – Quantity of juvenile feeds (meagre) 2021-2023 (Global)

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Rotifers Min (billion)	329	293	262	163	291	444	754	643	409	528
Rotifers Max (billion)	412	366	327	204	364	555	943	804	512	660
Enrichment Rotifers Min (L)	198	176	157	98	175	266	452	386	246	317
Enrichment Rotifers Max (L)	412	366	327	204	364	555	943	804	512	660
Artemia small (Kg cysts) -not enriched (Min)	132	117	105	65	117	178	302	257	164	211
Artemia small (Kg cysts) -not enriched (Max)	247	220	196	122	219	333	566	482	307	396
Artemia large enriched (kg cysts) (Min)	1894	1685	1504	937	1676	2552	4336	3697	2353	3035
Artemia large enriched (kg cysts) (Max)	2339	2080	1857	1157	2069	3151	5354	4564	2905	3747
Enrichment Artemia products (L)(Min)	568	505	451	281	503	766	1301	1109	706	910
Enrichment Artemia products (L) (Max)	935	832	743	463	828	1260	2142	1826	1162	1499
Co-feeding (200-300 µm) kg compound diet Min	659	586	523	326	583	888	1508	1286	818	1056
Co-feeding (200-300 µm) kg compound diet Max	988	879	785	489	874	1331	2262	1929	1228	1583
Weaning (300-600 µm) kg compound diet Min	4118	3663	3270	2038	3643	5547	9426	8036	5115	6598
Weaning (300-600 µm) kg compound diet Max	5765	5128	4578	2853	5100	7766	13196	11250	7161	9237
Nursery (0.5-1.1 mm or 0.3-3 g fish) kg compound diet Min	33105	29447	26291	16382	29288	44600	75783	64609	41125	53044
Nursery (0.5-1.1 mm or 0.3-3 g fish) kg compound diet Max	34422	30619	27337	17034	30453	46375	78799	67181	42761	55155
Broodstock feeds Min kg compound diet	1482	1319	1177	734	1311	1997	3393	2893	1841	2375
Broodstock feeds Max kg compound diet	2141	1905	1700	1060	1894	2885	4901	4179	2660	3431

Figure 67 – Estimated EU feed material demand for meagre (tonnes) (2023)



9.7. Rainbow trout

9.7.1. Life history

9.7.2. Production trends and statistics

Rainbow trout is a key species in global aquaculture, with annual production exceeding 650,000 tonnes. The European Union makes a significant contribution to this total. However, while global production has increased over the past decade, EU production has stabilised or even declined, resulting in a decrease in its share to approximately 15% of global output.

Rainbow trout (*Oncorhynchus mykiss*) is a key aquaculture species in the EU, with production reaching 190,000 tonnes in 2021 before declining to 171,000 tonnes in 2022 (STECF, 2025). Despite the decrease in volume, the production value rose from EUR 717 million to EUR 758 million over the same period. Five countries dominate the sector, accounting for nearly 80% of the EU’s trout production by volume and 70% by value. France and Italy are the largest producers, contributing 20% and 17% of total volume and 22% and 12% of total value, respectively. Denmark, Poland, and Spain follow, with shares of 16%, 14%, and 12% by volume, and 14%, 12%, and 10% by value, respectively. Most rainbow trout production in Europe occurs in freshwater systems, where fish are typically grown to market sizes between 300 and 500 g (with growing production of 500 g+ and 1000 g+ - so called salmon-trout – for filleting). However, a smaller segment of the industry focuses on marine cage farming, particularly in Denmark and Finland, where trout are raised in the Baltic Sea. These sea-reared trout develop a red flesh colour, positioning them as a direct competitor to salmon.

Large year-to-year fluctuations in the production of stocking material (juveniles at various developmental stages), as shown in the table below, suggest variability in the demand for fry feed. However, precise quantification of this phenomenon is not possible. The medium-term increase in the production of edible trout roe (as shown in the table below) may suggest a lengthening of the production cycle in part of the farming operations, leading to increased feed demand. However, the scale of this increase is not significant in the context of the sector’s overall feed requirements.

Figure 68 – Production volume and value of rainbow trout

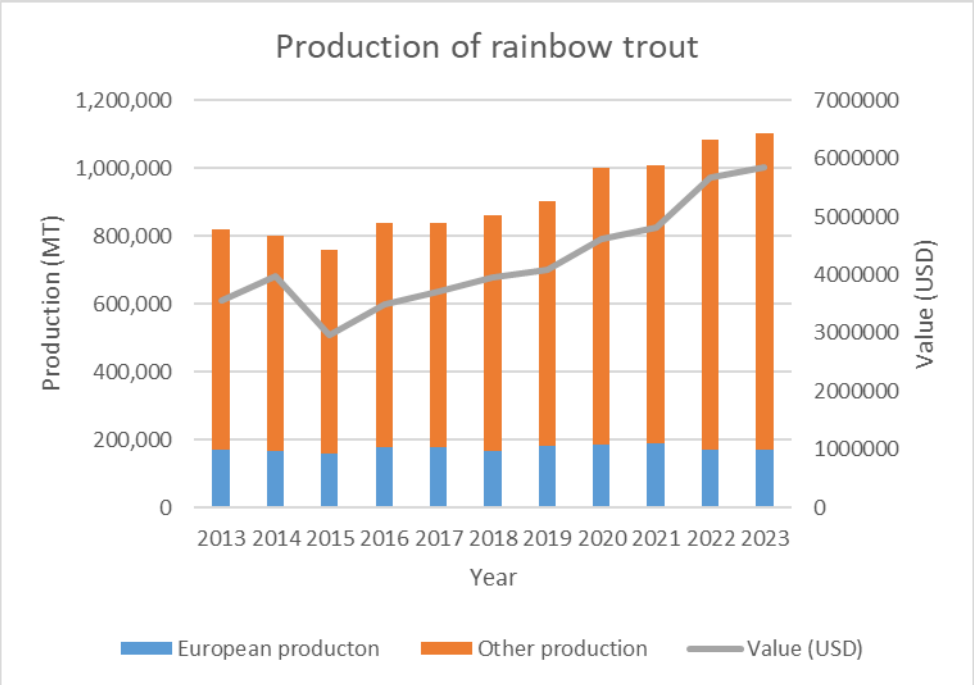


Table 55 – EU production (tonnes) of rainbow trout (production from aquaculture excluding hatcheries and nurseries)

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Global Production	802,800	758,392	838,337	839,777	862,837	902,251	1,001,228	1,010,417	1,084,275	1,105,245
EU-27	164,794	159,463	178,863	179,364	166,777	181,940	185,192	187,213	169,000	170,246
Belgium	175									
Bulgaria	2,865	2,322	3,092	2 956	4 793	3 830	3 318	4 168	3 453	4 640
Czechia	421	368	364	507	784	649	699	761	438	436
Denmark	30,296	32,164	30,307	30 546	28 265	30 852	29 404	24 928	25 052	21 960
Germany										
Estonia	570	559	680	702	804		870	712	678	785
Ireland	808	803	705	647		608	604	537	398	
Greece	1,611	1,759	1,644	1 989	2 127	1 898	1 936	1,911	2,140	2,104
Spain	15,104	16,154	17,209	16,829	16,002	15,914	15,806	18,056	16,465	17,515
France	29,086	28,830	33,725	33,070	33,150	34,540	36,720	33,978	31,506	27,409
Croatia	382	666	454	367	336	365	379			418
Italy	31,300	30,503	34,307	34,407	32,826	37,340	33,231	40,441	29,000	34,143
Cyprus	42	41	40	43	41	50	33	52	65	61
Latvia			82	92	113	50	61	92		
Lithuania	38	244	328	106	111	177	127	128	221	214
Hungary	61	42	67	54	72	76	95	74	61	76
Malta										
Netherlands										
Austria	1,277	1,185	1,220	1,303	1,358	1,417	1,524	1,736	1,691	1,920

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Poland	13,449	12,727	13,730	13,808	14,902	15,395	19,402	18,284	20,553	18,281
Portugal					380	676	607	245	408	174
Romania	1,152	1,345	1,109	1,840	2,251	2,537	2,636	2,747	3,107	3,527
Slovenia	647	656	833	737	964	937	864	869	733	587
Slovakia	870	926	1,080	1,024	1,014	993	747	1,202	1,050	1,063
Finland	12,357	13,862	13,376	13,579	13,180	14,204	14,293	13,551	15,253	14,426
Sweden	9,436	8,967	11,547	11,361	9,586	8,304	8,649	10,426		8,467

Data source: Eurostat Aquaculture production by species. (2025)

Table 56 – EU production (millions) of rainbow trout juveniles’ stage

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU-27	336.5	346.8	439.1	370.1	360.0	406.7	417.8	370.9	270.2	473.2
Belgium										
Bulgaria	16.0	15.6	15.4	21.2	24.7	27.1	21.0	9.7	11.2	11.4
Czechia	0.6	1.3	1.7	0.7	1.3	0.8	1.4	0.8	0.5	0.2
Denmark	83.8	92.7	79.9	85.9	70.1	76.3	77.4	78.4	69.8	87.8
Germany	20.2	17.5	14.1	15.5	15.2	13.1	15.8	16.3	13.8	14.4
Estonia					0.1					
Ireland	0.0									
Greece	7.7	7.5	7.0	6.0	9.3	6.1	6.8	6.2	7.7	12.5
Spain	40.1	38.6	38.9	56.3	36.8	31.2	24.7	58.9	13.9	0.0
France	3.0	9.3	11.6	12.9	19.4	20.0	15.2	15.4	50.9	31.9
Croatia	3.0	1.6	2.9	1.7	1.6	2.3	2.7	2.7	1.9	3.0
Italy	99.5	107.9	120.6	100.9	106.5	150.1	154.0	87.2		217.0
Cyprus	0.2	0.2	0.1	0.1	0.2	0.3	0.2	0.2	0.1	0.1
Latvia	0.4			0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania		0.1	0.0	0.0		0.0	0.0	0.0	0.0	0.1
Hungary	0.2	0.0	0.2	0.0	0.1	0.2	0.2	0.8		
Malta										
Netherlands										
Austria	4.4	4.1	4.3	4.7	5.0	4.9	4.7	4.9	4.5	5.3
Poland	34.6	28.6	45.4	36.4	47.1	48.4	64.1	61.3	66.8	66.3
Portugal									3.2	3.0
Romania	0.8	0.7	77.7	3.8	0.1	0.4	0.6			
Slovakia	1.0	2.1	1.3	1.1	1.7	2.5	1.2	1.1	2.1	2.0

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Finland	20.0	17.0	17.0	21.0	19.0	20.0	19.0	21.0	18.3	15.6
Sweden	1.0	2.0	1.0	2.0	2.0	3.0	8.8	6.0	5.5	2.6

Source: Eurostat Aquaculture production by species. (2025)

Table 57 – EU production (millions) of rainbow trout eggs for human consumption

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU-27	758.2	933.6	1 018.4	1 033.2	1 040.3	776.1	883.5	1 191.3	1 216.0	1 075.0
Denmark	342.3	436.8	514.0	524.6	563.9	323.5	376.9	667.0	652.5	570.6
Estonia	3.1	7.4	4.9	3.8	3.2	6.3	10.5	21.2		
Spain	20.1	28.6	28.1	28.2	35.9	36.2	63.7	81.2	75.5	51.2
Italy	1.2	1.3	1.2	11.4	12.4	16.0	13.2	25.0	38.0	48.0
Poland	0.6	0.5	1.1	0.2	0.9	4.4	2.2	6.9	7.0	6.7
Finland	391.0	459.0	469.0	465.0	424.0	389.6	417.0	390.0	443.0	398.5

9.7.3. FCR, feed demand and feed costs calculation

FCR data for rainbow trout farming show relatively low variability and based on data from key producers (Aller Aqua, Skretting, Biomar and the scientific literature (Hryszko, 2024; Kause *et al* 2022; Kajbaf *et al* 2024; Vandeputte *et al* 2022; and Altinterim 2019) we assume an average FCR = 1.13. Juvenile FCR – of 1.05 – were averaged from papers of Guzel and Arras, 2011 (1.09) and Silverstein (2006) (1.00). Historical improvements have reduced FCR by over 50% since the 1980s, with current values often reported between 0.77 and 1.0 under optimal conditions (Kause *et al* 2022; Kajbaf *et al* 2024; Vandeputte *et al* 2022; Altinterim, 2019). Selective breeding has contributed significantly to FCR reduction, with genetic gains accounting for about one-third of the total improvement. Each generation of selective breeding can improve FCR by approximately 1.7%, leading to cumulative gains over time (Kause *et al* 2022; Kause *et al* 2016; Vandeputte *et al* 2022).

Replacing fish meal with plant-based proteins (e.g., fermented soybean meal) can maintain low FCRs (around 1.0) if up to 40% of fish meal is replaced. Higher replacement levels may increase FCR and reduce growth (Choi *et al* 2020; Vandeputte *et al* 2022). High stocking densities and suboptimal conditions can increase FCR, while practices like providing water currents can help maintain lower FCRs by reducing stress and improving energy use (Larsen *et al* 2012). However, when estimating feed consumption, it is necessary to account for typical production conditions, which also involve certain losses during the production process. Therefore, an FCR of 1.13 is more appropriate for calculating the ratio between production and feed use (Hryszko, 2024).

An economic review of EUMOFA (2021b) provides feed costs, and production values of several EU countries trout production, from which an average feed cost of EUR 1221/tonne can be calculated.

Table 58 – Rainbow trout (adult) food demand (2013-2023)

Country (Name)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Austria	1,322	1,277	1,185	1,220	1,302	1,358.1	1,416.67	1,523.54	1,735.66	1,691.3	1,919.76
Belgium	173	175	50	0	0	0	0	0	0	0	0
Bulgaria	30,42.3	3,311.8	2,322.04	3,096.26	2,213.02	3828.14	3,170.03	4,820.29	4,535.72	3,449.04	4,639.55
Croatia	348.9	381.78	666	454.4	367.1	335.56	364.5	332.2	327.7	410.2	418.07
Cyprus	54.7	41.6	40.68	39.7	43.5	41	50	33	51.8	64.7	61.1
Czechia	438.7	421	368	364	507	784	649	699	761	438	436
Denmark	33,840	30,733	32,345.7	31,087	33,036	29737	30,851.84	3,2821	28,375.3	24,470	24,542
Estonia	465.49	569.6	559	680.4	702.21	804.15	926.97	869.92	711.87	677.51	784.78
Finland	12,242	12,357	13,861	13,376	13,579.6	13180.1	14,203.8	14,293.3	13,550.7	15,253	14,426.1
France	30,818	29,346.9	23,488.7	35,674.1	34,905.8	33150.1	36,331.04	36,719.92	33,979.14	33,081.68	28,624.41
Germany	9,601	9,957	8,527	8,640	8,452	7852	7,841	7946	7712	7,938	7,620
Greece	2,016.5	1,611.4	1,758.7	1,644.3	1,988.7	2126.5	1,897.9	1,935.73	1,911.2	1,900	2,103.53
Hungary	52	61	42	58	54.1	72.2	76.38	94.95	73.5	61.22	75.55
Ireland	908	808	803	705	647	557	608	604	537	398	475
Italy	35,059	31,300.07	31,300	35,000	35,000	32825.65	37,390	33,230.8	40,441.1	29,000	34,143.3
Latvia	3.5	38.13	134.14	82.17	92.2	113.87	50.04	60.71	91.89	27.9	36
Lithuania	115.12	109.48	278.01	331.94	106.15	111.2	182.43	132.78	130.55	223.4	216.51
Netherlands (Kingdom of the)	45	45	45	45	45	45	50	50	50	50	0
Poland	11,554	14,263	12,726.9	13,730.07	13,807.61	14902.33	15,395.38	19,401.81	18,286.25	20,552.83	18,281.02
Portugal	773.7	751.07	888.71	675.73	654.65	654.65	654.65	894	857	408	298.5

Country (Name)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Romania	1,072	1,154.64	1,344.83	1109	1,840.42	2251.02	2,617.65	2,636	2,536	3,107.16	3,526.98
Slovakia	735	887	926	1,115.3	1,019.3	1013.2	993.24	774	1,200	1,050	1049
Slovenia	582	647.2	656	833.4	737.3	964.4	937.1	863.4	869	732.6	586.86
Spain	15,867.9	15,110.67	16,179.1	17,353.85	16,902.2	10483.8	16,972.26	15,805.72	18,055.56	16,465.49	17,514.98
Sweden	9757	9,436	8,967	1,1547	1,1361	9586	8310	8,650	1,0433	7,550	8,467
Total EU Species Feed Demand	193,102	186,218	180,193	202,115	202,681	188,458	205,592	209,267	211,551	190,970	192,378
Global Species Feed Demand	928,556	907,164	856,983	947,321	948,948	975,006	1,019,544	1,131,387	1,141,771	1,225,231	1,248,927

Table 59 – Rainbow trout (juvenile*) Food demand 2014-2023

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU-27	2,381	2,454	3,108	2,619	2,548	2,878	2,957	2,625	1,912	3,349
Bulgaria	113	110	109	150	175	192	149	69	79	81
Czechia	4	9	12	5	9	6	10	6	4	1
Denmark	593	656	565	608	496	540	548	555	494	621
Germany	143	124	100	110	108	93	112	115	98	102
Estonia					1					
Greece	54	53	50	42	66	43	48	44	54	88
Spain	284	273	275	398	260	221	175	417	98	0
France	21	66	82	91	137	142	108	109	360	226
Croatia	21	11	21	12	11	16	19	19	13	21
Italy	704	764	853	714	754	1,062	1,090	617		1,536
Cyprus	1	1	1	1	1	2	1	1	1	1
Lithuania		1								1
Hungary	1		1		1	1	1	6		
Austria	31	29	30	33	35	35	33	35	32	38
Poland	245	202	321	258	333	343	454	434	473	469
Portugal									23	21
Romania	6	5	550	27	1	3	4			
Slovakia	7	15	9	8	12	18	8	8	15	14
Finland	142	120	120	149	134	142	134	149	130	110
Sweden	7	14	7	14	14	21	62	42	39	18

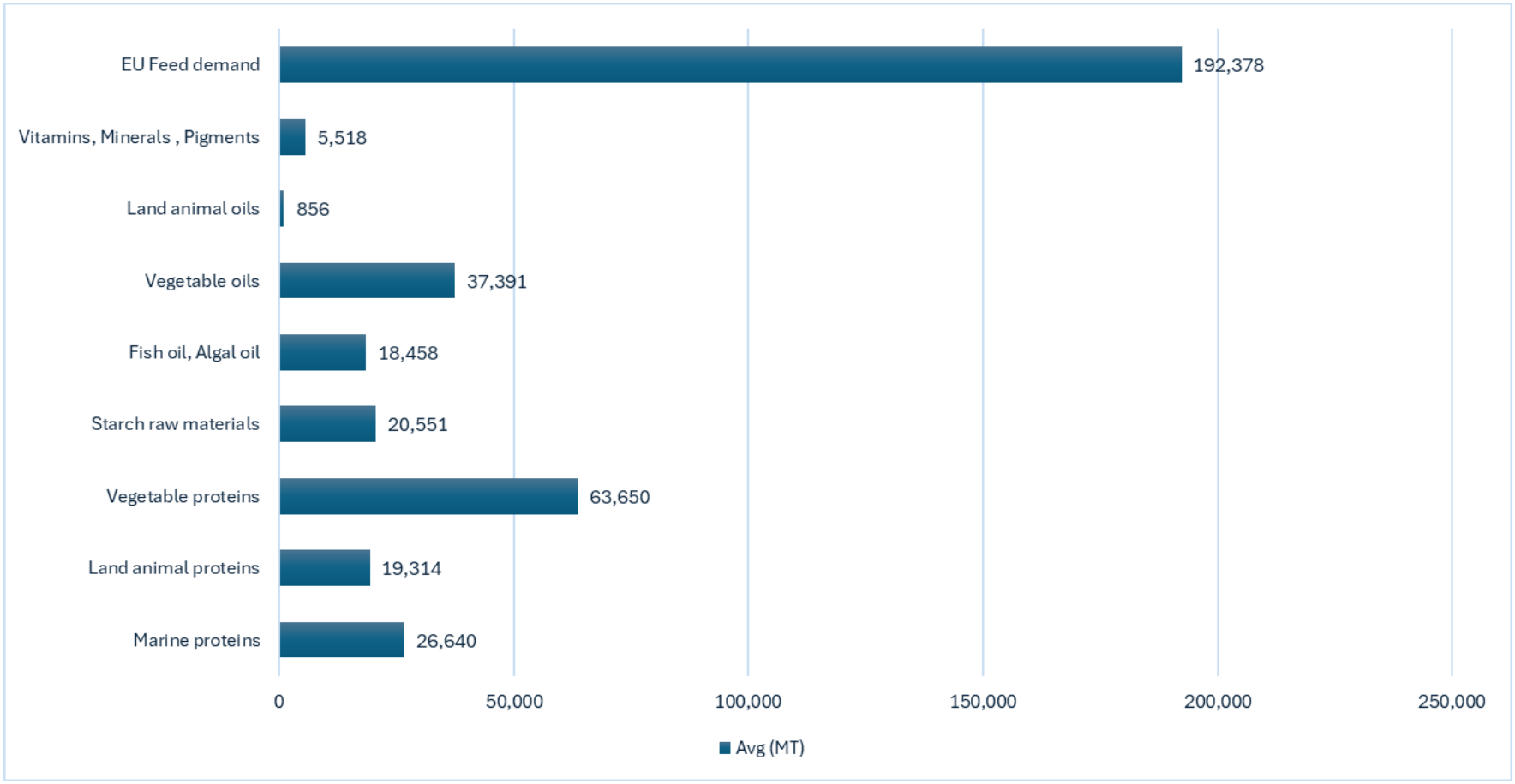
* Based on juvenile size of 6.74g (Guzel and Arras, 2011; Silverstein, 2006)

9.7.4. Diet composition

Table 60 – Typical diet composition for rainbow trout

Material	Sources
Vegetable protein sources	Plant proteins
Vegetable oils	Vegetable oils
Carbohydrate sources	Cereal products (grains)
Marine protein sources	Fish meal
	Krill meal
	Marine by-products (fishery by-products)
Terrestrial protein sources	Single cell proteins
	Blood meal
	Non-marine by-products (terrestrial)
	Processed animal proteins
Marine oils	Fish oil
Land based oils	Processed animal oils
Micro materials	Functional materials (additives)
	Vitamins and minerals

Figure 69 – Estimated EU feed material demand for rainbow trout (tonnes) (2023)



9.8. Whiteleg shrimp

9.8.1. Life history

Whiteleg shrimp (*Litopenaeus vannamei*) represents the most widely cultivated shrimp species in global aquaculture. Originally native to the eastern Pacific coasts of Central and South America, it has been introduced to the aquaculture industry worldwide due to its adaptability, rapid growth, and economic value. Its prominence in the shrimp farming industry is primarily attributed to its ability to thrive in a wide range of environmental conditions and its suitability for various aquaculture systems.

In terms of environmental adaptability, whiteleg shrimp can tolerate a broad range of salinity levels, from as low as 0.5 ppt to over 45 ppt, making it viable for farming in both inland and coastal areas. It also grows well in water temperatures between 20 and 35°C. These characteristics have allowed the species to become the dominant choice for shrimp aquaculture in countries such as Ecuador, India, Vietnam, Indonesia, and China.

Aquaculture systems used for whiteleg shrimp range from extensive to highly intensive operations. In extensive systems, shrimp are grown in large ponds with minimal inputs and rely on natural productivity for nutrition. Semi-intensive systems use moderate stocking densities, aeration, and supplementary feeding to enhance growth. Intensive systems involve high stocking densities often exceeding 100 PL (postlarvae) per square meter along with continuous aeration and high-quality commercial feeds to maximize production. Additionally, advanced systems such as biofloc technology and recirculating aquaculture systems (RAS) are being increasingly adopted to improve water quality, reduce environmental impact, and enhance biosecurity.

The breeding of whiteleg shrimp occurs in controlled reproduction conditions in hatcheries. Broodstock are kept in captivity and induced to spawn, enabling year-round seed production. Hatcheries rear the shrimp from eggs through various larval stages such as nauplius, zoea, mysis to postlarvae, which are then transferred to grow-out facilities.

Whiteleg shrimp are known for their fast growth rates, reaching market sizes of 20 to 25 grams within 90 to 120 days, depending on culture conditions. They also exhibit relatively high survival rates when managed properly and are efficient at converting feed into body mass.

In terms of nutrition, whiteleg shrimp are omnivorous and typically fed pelleted diets containing high percentage of protein (30 to 40%). These diets are formulated to support optimal growth and feed efficiency.

9.8.2. Production trends and statistics

Over the past decade, the shrimp industry has undergone significant growth to keep up with increasing global trade demands. In response, farmers have adopted more controlled and intensive farming systems that incorporate enhanced biosecurity measures to minimize the risk of disease outbreaks. Key contributors to this intensification have been advancements in nutrition and selective breeding programs, both of which play a vital role in the industry's ongoing development (Emerenciano *et al* 2022). Among the many commercially valuable aquaculture species, shrimp is considered one of the most efficient to farm, owing to its rapid growth, short production cycle, strong consumer appeal, and high demand in both local and international markets, along with its substantial export value (Ayisi *et al* 2017).

Despite the exponential growth of the global shrimp industry, European production remains minimal, accounting for less than 0.01% of total global output. In 2022, European production peaked at 141 tonnes but experienced a decline in 2023, reaching only 101 tonnes. The leading producers within Europe are Spain, Germany, Austria, and Bulgaria.

In contrast, global shrimp production continues to show consistent growth, surpassing 7 Mt in 2023. The largest contributors are China and India, which together account for more than one-third of the total global output. Ecuador follows with an annual production of approximately 1.2 Mt. Additionally, Indonesia, Vietnam, and Thailand collectively contribute over 2 Mt. Overall, Asia remains the dominant region in shrimp production, far exceeding the output of other continents.

Table 61 – Whiteleg shrimp global production (tonnes) (2013-2023)

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Austria	0	0	0	0	0	1	5	15	45	22	29
Belize	7,080	7,164	4,150	1,090	500	500	500	465	530	650	800
Brazil	64,678	65,028	70,521	52,127	41,078	45,750	54,336	63,170	78,637	113,301	127,466
Brunei Darussalam	0	0	0	0	0	0	0	2,785	4,430	4,709	1,402
Bulgaria	0	0	0	0	0	0	0	5	18	23	23
Cabo Verde	0	0	0	0	0	0	5	22	28	35	35
China	1,338,958	1,473,007	1,519,409	1,628,638	1,672,287	1,760,341	1,815,550	1,862,937	1,977,399	2,098,630	2,238,390
Colombia	4,545	2,862	2,484	3,000	4,000	5,397	5,582	5,284	3,863	4,965	4,900
Costa Rica	2,890	2,973	2,682	3,000	3,000	2,700	2,500	2,200	2,600	1,122	1,509
Cuba	4,116	4,121	4,719	5,044	5,631	6,474	6,657	4,724	4,725	1,908	931
Dominican Republic	250	450	450	400	300	300	300	300	300	320	320
Ecuador	304,000	340,000	403,000	422,000	460,000	560,000	679,985	760,879	890,386	1,109,200	1,220,200
Egypt	0	0	0	101	135	155	123	2,146	3,429	1,665	1,665
El Salvador	771	812	1,084	1,124	1,513	1,851	1,554	1,040	882	900	900
Germany	0	0	0	0	0	0	24	25	31	31	34
Greece	0	0	0	0	0	0	0	0	0	15	15
Guam	10	10	10	10	10	10	12	14	10	10	10
Guatemala	13,764	13,891	14,268	14,909	16,455	17,273	19,500	20,568	16,472	25,083	26,420
Guyana	0	0	0	0	0	0	0	0	0	0	340
Honduras	30,500	32,000	25,000	23,000	31,500	31,500	32,100	32,451	33,568	35,293	53,571

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
India	211,200	305,251	416,347	461,302	583,400	622,000	724,267	894,772	997,263	973,540	1,153,339
Indonesia	376,189	442,379	409,899	498,174	757,807	708,680	677,632	696,570	770,335	731,250	764,239
Iran (Islamic Republic of)	12,698	22,475	17,795	21,331	32,332	47,859	46,114	48,450	57,799	57,800	55,000
Jamaica	50	0	0	0	0	0	0	0	0	0	0
Kazakhstan	0	0	0	0	0	0	0	0	0	10	20
Kuwait	0	0	0	0	0	0	0	0	0	2	2
Lebanon	25	10	10	10	10	12	12	8	8	10	10
Malaysia	45,474	57,181	48,284	37,593	35,648	36,007	38,767	35,149	38,377	39,558	34,375
Mexico	60,292	86,973	130,361	127,814	150,030	157,934	170,076	214,028	181,809	197,805	193,716
Myanmar	0	0	0	0	0	0	0	0	4,412	8,408	8,400
Nicaragua	26,368	30,528	24,506	21,178	24,888	29,458	29,490	29,459	30,958	31,525	32,000
Northern Mariana Islands	20	23	23	23	23	23	23	20	20	20	20
Oman	0	0	0	0	0	0	0	0	0	1,078	2,917
Panama	6,954	8,611	7,861	6,724	7,522	6,409	5,153	2,224	5,195	9,086	8,592
Peru	17,883	21,484	22,183	20,441	27,492	39,153	50,820	35,233	36,482	45,184	42,927
Philippines	7,597	7,626	8,752	10,233	13,965	12,527	19,152	20,633	26,211	35,943	36,371
Qatar	0	0	0	0	0	0	0	1	36	37	10
Republic of Korea	3,785	4,488	5,515	5,791	5,144	4,480	7,542	8,124	9,545	9,504	6,996
Saudi Arabia	0	12,980	17,295	24,055	39,200	56,100	60,891	46,630	60,712	60,800	72,780
Seychelles	0	0	0	0	0	0	0	0	0	0	29
Singapore	0	0	15	7	12	13	6	6	79	108	74

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Spain	1	4	6	10	8	15	2	30	45	50	0
Sri Lanka	0	0	0	0	0	0	0	2,640	10,535	13,277	9,378
Suriname	77	74	69	29	20	10	10	10	10	10	10
Switzerland	0	0	0	0	0	0	30	30	30	30	30
Taiwan Province of China	13,207	12,643	10,020	12,376	9,228	7,979	10,072	8,057	9,845	9,442	9,254
Thailand	310,705	263,245	281,918	314,018	346,309	357,933	378,508	373,633	370,757	369,320	370,260
Timor-Leste	0	0	0	0	0	8	10	12	12	12	12
Tunisia	0	0	0	2	2	1	1	0	0	0	0
Türkiye	0	0	0	0	0	0	0	0	4	19	18
United Arab Emirates	0	0	0	0	0	0	0	0	0	1	3
United States of America	1,522	2,209	1,805	1,633	1,633	2,035	2,035	2,035	2,035	2,035	1,263
Vanuatu	0	0	8	11	10	10	10	0	0	0	0
Venezuela (Bolivarian Republic of)	20,000	22,500	13,627	21,462	22,500	21,500	25,000	31,250	44,578	43,800	54,000
Viet Nam	236,242	352,722	339,489	380,000	439,023	475,000	585,866	621,199	666,139	801,804	821,978
EU27	1	4	6	10	8	16	31	75	139	141	101
Global	3,121,851	3,595,723	3,803,567	4,118,658	4,732,615	5,017,399	5,450,222	5,829,232	6,340,586	6,839,347	7,356,982

Source: FAO (2025c)

Figure 70 – Global shrimp production by country (2023)

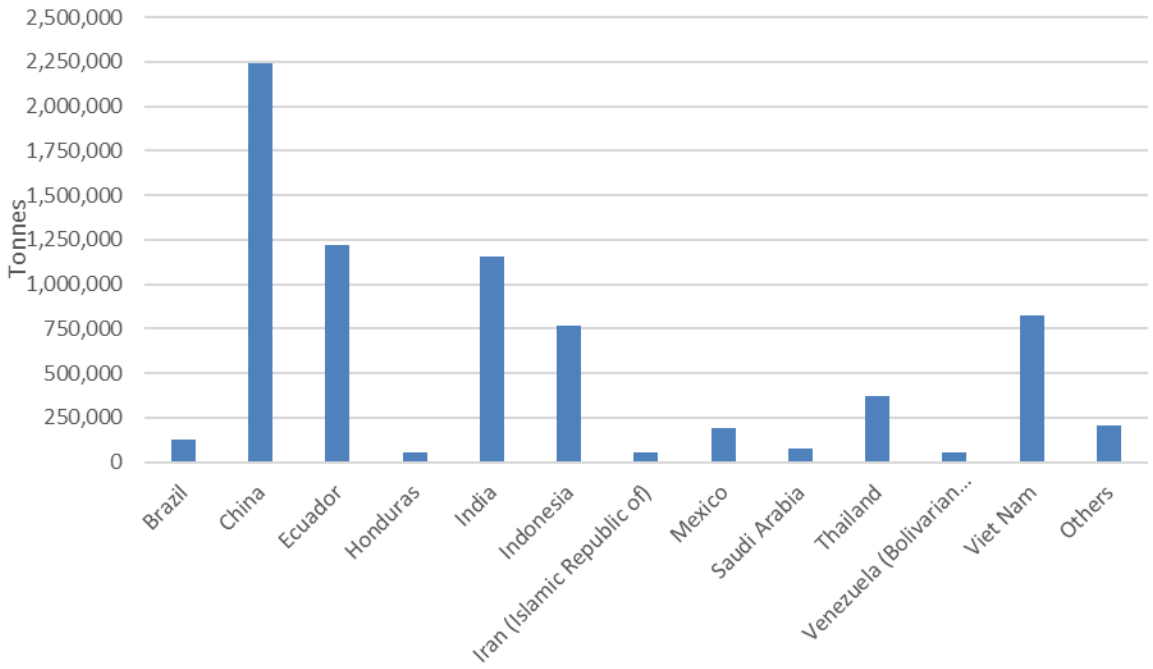
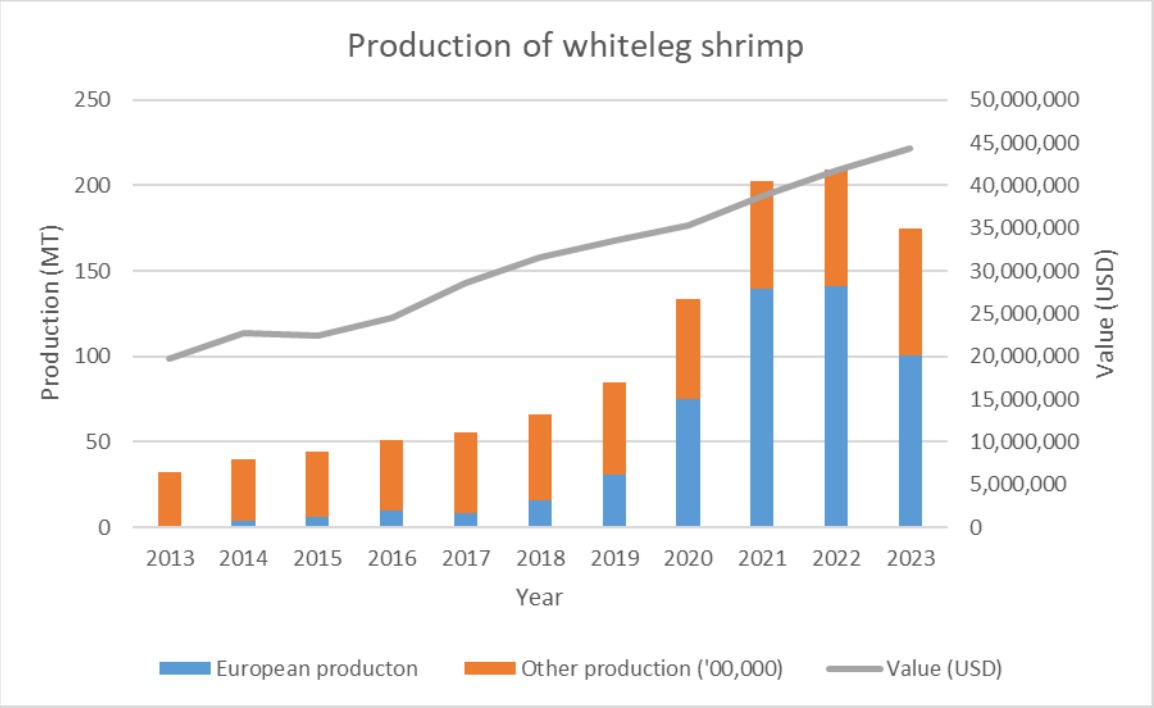


Figure 71 – Trend in production volume and value of whiteleg shrimp



9.8.3. FCR, feed demand and feed costs calculation

Information regarding the adult FCR values was obtained from IAFFD (2024). FCR was calculated as an average across three life stages—starter, grower, and finisher—resulting in a value of 1.22. The FCR of stages before these phases (i.e. postlarvae) of 1.15 was averaged from the control treatments of Barreto *et al* (2023a) (0.9) and Barreto *et al,* (2023b) (1.4).

Given the paucity of data on commercial production of whiteleg shrimp in the EU the average cost of feed had to be taken from an economic analysis of global production (Nunes *et al,* 2022). Assuming a fishmeal inclusion rate of 10% - indicated in table 11, the cost of USD 905 or EUR 772/t is obtained. This is lower than the value for other EU species’ diets (Table 1), which may reflect the global vs EU economics, supply chains and scale of production.

Since the EU hatchery production is not recorded (juveniles are brought into the EU from non-EU countries) the harvest production was divided by 0.00225kg (the approximate harvest size of whiteleg shrimp (Zhao et al, 2025)) to get the approximate number of individuals and then the demand for food was estimated using formula 2a and 2b.

The global feed demand in the shrimp industry has grown significantly in recent years due to the expansion of aquaculture operations and the increasing global consumption of shrimp. As shrimp farming intensifies to meet market needs, the reliance on high-quality, nutritionally balanced feed has become crucial for maximizing growth rates, improving feed conversion ratios, and ensuring overall shrimp health. The demand is also influenced by the shift toward more sustainable and traceable feed materials, driven by environmental concerns and regulatory pressures. Consequently, feed manufacturers are innovating with alternative protein sources, such as insect meal and plant-based options, to reduce dependence on traditional fishmeal and fish oil.

9.8.4. Diet composition

Table 62 – Typical diet composition of whiteleg shrimp

Material	Larvae	Juvenile	Grower
Carbohydrate sources	Wheat flour	Wheat flour	Wheat flour
			Maize/rice bran
Marine protein sources	Fishmeal	Fishmeal	Fishmeal
	Squid/shrimp meal	Squid/shrimp meal	
Terrestrial protein sources	Soybean meal	Soybean meal	Soybean meal
Marine oils	Fish oil	Fish oil	Fish oil

Material	Larvae	Juvenile	Grower
Micro materials	Vitamin & mineral premix	Vitamin & mineral premix	Vitamin & mineral premix
	Probiotics/binders	Probiotics/binders	Probiotics/binders
	Lecithin	Lecithin	Lecithin
		Calcium phosphate	Calcium phosphate

Table 63 – Global feed demand of whiteleg shrimp

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Austria	0	0	0	0	0	1,2	6	18	54	26,4	34,8
Belize	8,496	8,597	4,980	1,308	600	600	600	558	636	780	960
Brazil	77,614	78,034	84,625	62,552	49,294	54,900	65,203	75,804	94,364	135,961	152,959
Brunei Darussalam	0	0	0	0	0	0	0	3,342	5,316	5,651	1,682
Bulgaria	0	0	0	0	0	0	0	6	21,6	27,6	27,6
Cabo Verde	0	0	0	0	0	0	6	26,4	33,6	42	42
China	1,606,750	1,767,608	1,823,291	1,954,366	2,006,744	2,112,409	2,178,660	2,235,524	2,372,879	2,518,356	2,686,068
Colombia	5,454	3,434	2,981	3,600	4,800	6,476	6,698	6,341	4,636	5,958	5,880
Costa Rica	3,468	3,568	3,218	3,600	3,600	3,240	3,000	2,640	3,120	1,346	1,811
Cuba	4,939	4,945	5,663	6,053	6,757	7,769	7,988	5,669	5,670	2,290	1117,2
Dominican Republic	300	540	540	480	360	360	360	360	360	384	384
Ecuador	364,800	408,000	483,600	506,400	552,000	672,000	815,982	913,055	1,068,463	1,331,040	1,464,240
Egypt	0	0	0	121,2	162	186	147,6	2,575	4,115	1,998	1,998
El Salvador	925,2	974,4	1,301	1,349	1,816	2,221	1,865	1,248	1058,4	1080	1080
Germany	0	0	0	0	0	0	28,8	30	37,2	37,2	40,8
Greece	0	0	0	0	0	0	0	0	0	18	18
Guam	12	12	12	12	12	12	14,4	16,8	12	12	12
Guatemala	16,517	16,669	17,122	17,891	19,746	20,728	23,400	24,682	19,766	30,100	31,704
Guyana	0	0	0	0	0	0	0	0	0	0	408
Honduras	36,600	38,400	30,000	27,600	37,800	37,800	38,520	38,941	40,282	42,352	64,285
India	253,440	366,301	499,616	553,562	700,080	746,400	869,120	1,073,726	1,196,716	1,168,248	1,384,007
Indonesia	451,427	530,855	491,879	597,809	909,368	850,416	813,158	835,884	924,402	877,500	917,087
Iran (Islamic Republic of)	15,238	26,970	21,354	25,597	38,798	57,431	55,337	58,140	69,359	69,360	66,000
Kazakhstan	0	0	0	0	0	0	0	0	0	12	24
Kuwait	0	0	0	0	0	0	0	0	0	2,4	2,4

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Lebanon	30	12	12	12	12	14,4	14,4	9,6	9,6	12	12
Malaysia	54,569	68,617	57,941	45,112	42,778	43,208	46,520	42,179	46,052	47,470	41,250
Mexico	72,350	104,368	156,433	153,377	180,036	189,521	204,091	256,834	218,171	237,366	232,459
Myanmar	0	0	0	0	0	0	0	0	5,294	10,090	10,080
Nicaragua	31,642	36,634	29,407	25,414	29,866	35,350	35,388	35,351	37,150	37,830	38,400
Northern Mariana Islands	24	27,6	27,6	27,6	27,6	27,6	27,6	24	24	24	24
Oman	0	0	0	0	0	0	0	0	0	1,294	3,500
Panama	8,345	10,333	9,433	8,069	9,026	7,691	6,184	2,669	6,234	10,903	10,310
Peru	21,460	25,781	26,620	24,529	32,990	46,984	60,984	42,280	43,778	54,221	51,512
Philippines	9,116	9,151	10,502	12,280	16,758	15,032	22,982	24,760	31,453	43,132	43,645
Qatar	0	0	0	0	0	0	0	1,2	43,2	44,4	12
Republic of Korea	4,542	5,386	6,618	6,949	6,173	5,376	9,050	9,749	11,454	11,405	8,395
Saudi Arabia	0	15,576	20,754	28,866	47,040	67,320	73,069	55,956	72,854	72,960	87,336
Seychelles	0	0	0	0	0	0	0	0	0	0	34,8
Singapore	0	0	18	8,4	14,4	15,6	7,2	7,2	94,8	129,6	88,8
Spain	1,2	4,8	7,2	12	9,6	18	2,4	36	54	60	0
Sri Lanka	0	0	0	0	0	0	0	3,168	12,642	15,932	11,254
Suriname	92,4	88,8	82,8	34,8	24	12	12	12	12	12	12
Switzerland	0	0	0	0	0	0	36	36	36	36	36
Taiwan Province of China	15,848	15,172	12,024	14,851	11,074	9,575	12,086	9,668	11,814	11,330	11,105
Thailand	372,846	315,894	338,302	376,822	415,571	429,520	454,210	448,360	444,908	443,184	444,312
Timor-Leste	0	0	0	0	0	9,6	12	14,4	14,4	14,4	14,4
Tunisia	0	0	0	2,4	2,4	1,2	1,2	0	0	0	0
Türkiye	0	0	0	0	0	0	0	0	4,8	22,8	21,6
United Arab Emirates	0	0	0	0	0	0	0	0	0	1,2	3,6

Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
United States of America	1,826	2,651	2,166	1,960	1,960	2,442	2,442	2,442	2,442	2,442	1,516
Vanuatu	0	0	9,6	13,2	12	12	12	0	0	0	0
Venezuela (Bolivarian Republic of)	24,000	27,000	16,352	25,754	27,000	25,800	30,000	37,500	53,494	52,560	64,800
Viet Nam	283,490	423,266	407,387	456,000	526,828	570,000	703,039	745,439	799,367	962,165	986,374
EU27	1	4	7	12	10	20	37	92	170	172	123
Global Total	3,746,221	4,314,869	4,564,278	4,942,392	5,679,138	6,020,878	6,540,266	6,995,080	7,608,701	8,207,220	8,828,380

Table 64 – EU Feed demand (tonnes) of whiteleg shrimp (juveniles*) 2024-2023

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU shrimp production in tonnes	1.00	3.50	5.95	9.50	8.30	16.00	30.50	75.00	139.34	140.93	100.86
N of shrimp produced per year (average size of 22.5g)	44444	155556	264444	422222	368889	711111	1355556	3333333	6192889	6263556	4482667
N of shrimp produced considering a 100% survival rate	62222	217778	370222	591111	516444	995556	1897778	4666667	8670044	8768978	6275733
Tonnes of artemia	0.004	0.014	0.023	0.037	0.032	0.062	0.119	0.293	0.544	0.550	0.394

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Artemia enrichment requirement based on Inve S. presso (tonnes)	0.002	0.01	0.01	0.02	0.02	0.03	0.07	0.16	0.30	0.30	0.22
Rotifer enrichment requirement based on Inve S. presso (tonnes)	0.001	0.002	0.003	0.005	0.004	0.008	0.016	0.038	0.071	0.072	0.052

Figure 72 – Global feed demand of whiteleg shrimp

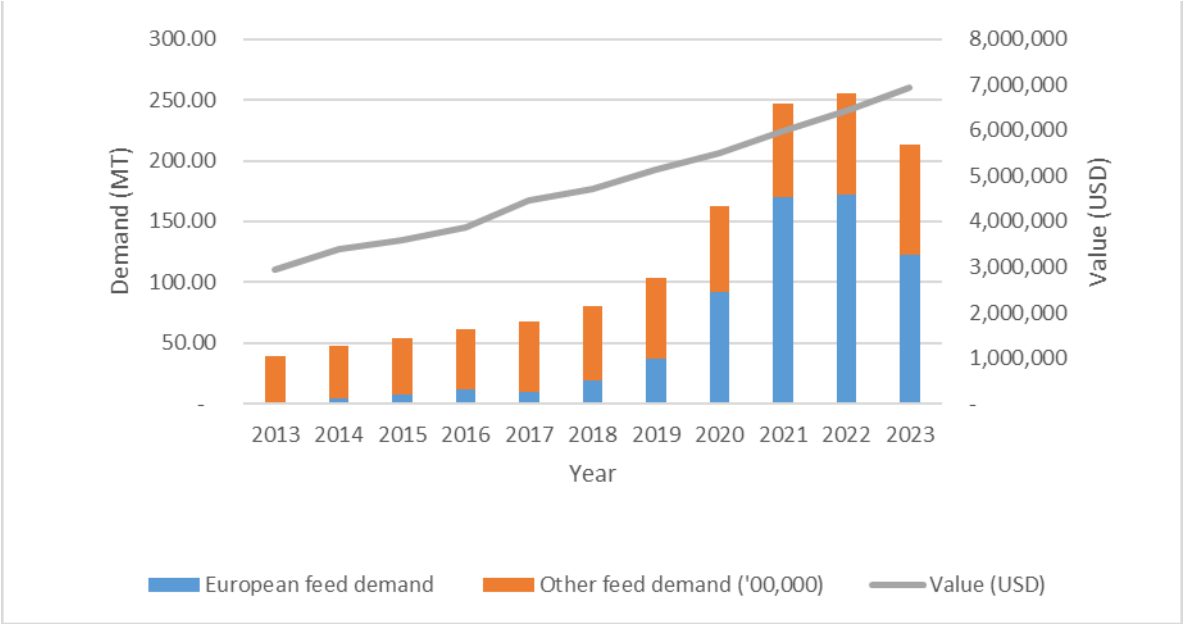
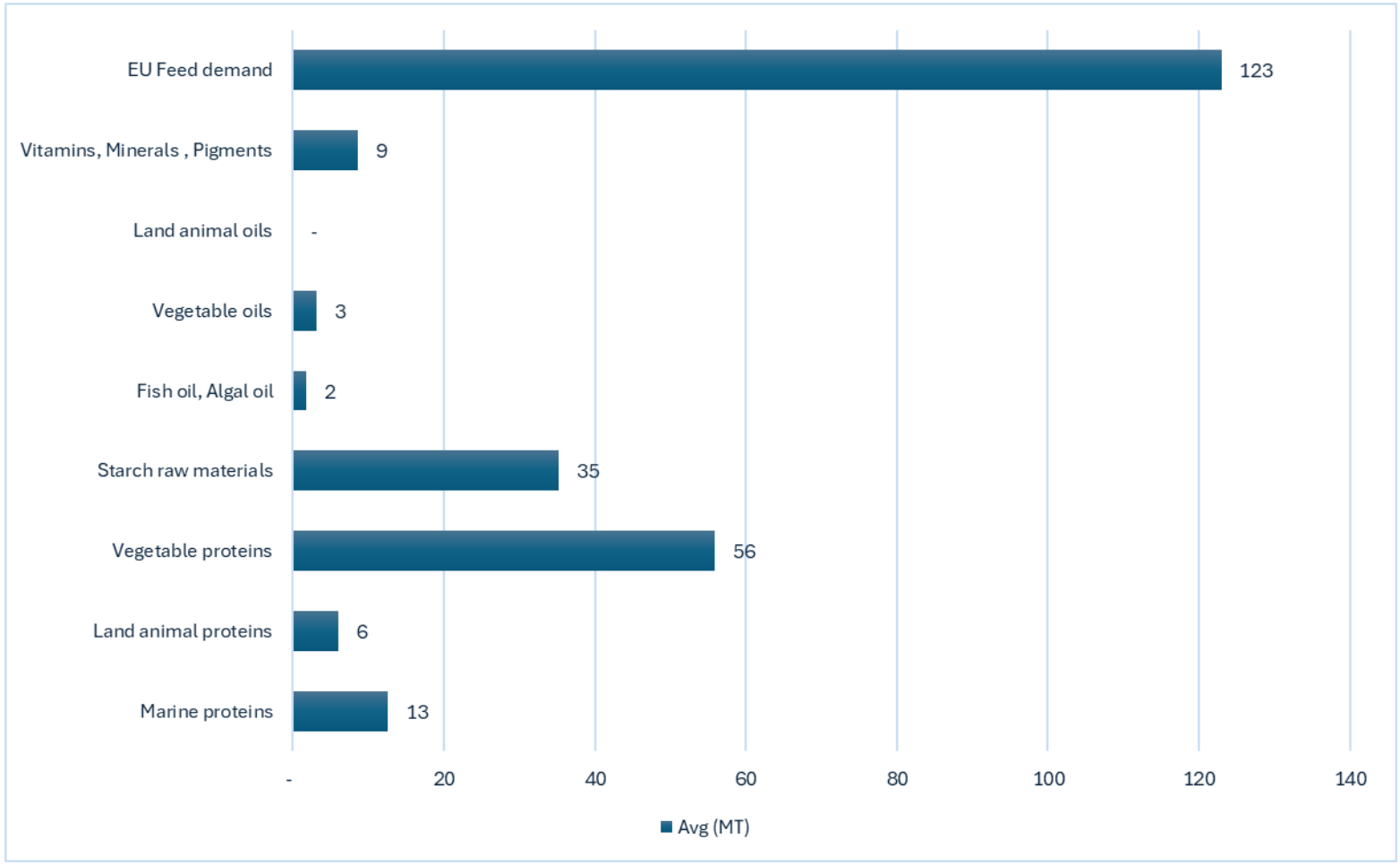


Figure 73 – Estimated EU feed material demand for whiteleg shrimp (tonnes) (2023)



9.9. Sole

9.9.1. Life history

Sole production generally refers to two species Common sole, also known as Dover sole (*Solea solea*, Linnaeus, 1758, a.k.a. *Solea vulgaris*) and Senegalese sole (*Solea senegalensis*, Kaup, 1858). The two species are almost indistinguishable to consumers and are often combined in production and market statistics.

From a biological point of view, the two sole species are very similar (Dinis *et al* 1999). They are both demersal flatfish belonging to the Soleidae family. *S. solea* is distributed throughout the Eastern Atlantic, from Norway to Senegal, including the Mediterranean, while *S. senegalensis* inhabits similar regions with a focus on the southern ranges. Both species are highly prised for their delicate flavour and firm white flesh. Their benthic nature and adaptability to environmental conditions make them well-suited for aquaculture.

Sole species live on sandy or muddy seabed in coastal zones, estuaries, and lagoons. They tolerate a broad salinity range and variable temperatures. Spawning typically occurs in summer, especially June, with water temperatures between 15°C and 20°C. Larvae of the two species are very difficult to distinguish. Both species are gonochoric, females attain sexual maturity at age 3 for Senegalese sole and at age 4 for common sole, with a total length of 32 cm and 27–30 cm, respectively. Female sole can reach up to 40 cm after 5 years with a maximum observed length of 60 cm while males rarely grow longer than 40 cm (MCS, 2014). Fecundity is very similar in both species as well as life cycles, being long-lived flatfishes that can reach an age of over 40 years. The most important items in the diet of *S. solea* and *S. senegalensis* are Crustacea, Polychaeta and Bivalvia (Teixeira and Cabral, 2010).

The interest in sole farming has been stimulated largely by a desire, if not a need, for the existing marine fish farming industry to diversify (Howell, 1997). A revival of interest in the possibility of farming sole has been stimulated by indications of market saturation for species such as sea bass and sea bream.

Senegalese sole aquaculture has advanced in Spain and Portugal, particularly using land-based recirculating aquaculture systems (RAS). Its adaptability and high value support its economic viability, though challenges include slow growth and handling sensitivity such as tolerance to crowding which is a requirement for economic viability of intensive systems. It is clear that high stocking densities can cause adverse effects on growth through poor water quality, but with sole

even if those conditions are negated, growth can still diminish significantly (Howell, 1998).

Efforts are ongoing to improve performance through diet, environmental optimization and selective breeding. Sole species are considered luxury seafood in Europe, attracting premium prices. Their tender flesh and mild flavour are well-regarded in culinary markets. Aquaculture helps meet increasing demand and reduce wild stock exploitation. Ongoing research is key to improving efficiency and sustainability.

9.9.2. Production trends and statistics

It appears that in the coming years almost all farmed sole production will come from Senegalese sole, in part due to better growth at higher temperatures than for common sole and since it takes place in southern European countries where Senegalese sole is found (Bjørndal *et al* 2015).

In 2013 EU was holding 100% of the global market share for both species. The highest production values were found in Portugal and Spain with 154 and 440 tonnes, with sporadic attempts from other EU countries like Italy and Greece. EU has maintained its market share for the past 10 years by tripling their capabilities to 1,800 tonnes in 2023. Globally, the main contributors to the fish species growth are Spain, Portugal and recently Iceland.

Figure 74 – EU and Global production volumes (sole spp.) in (tonnes) over a ten-year period

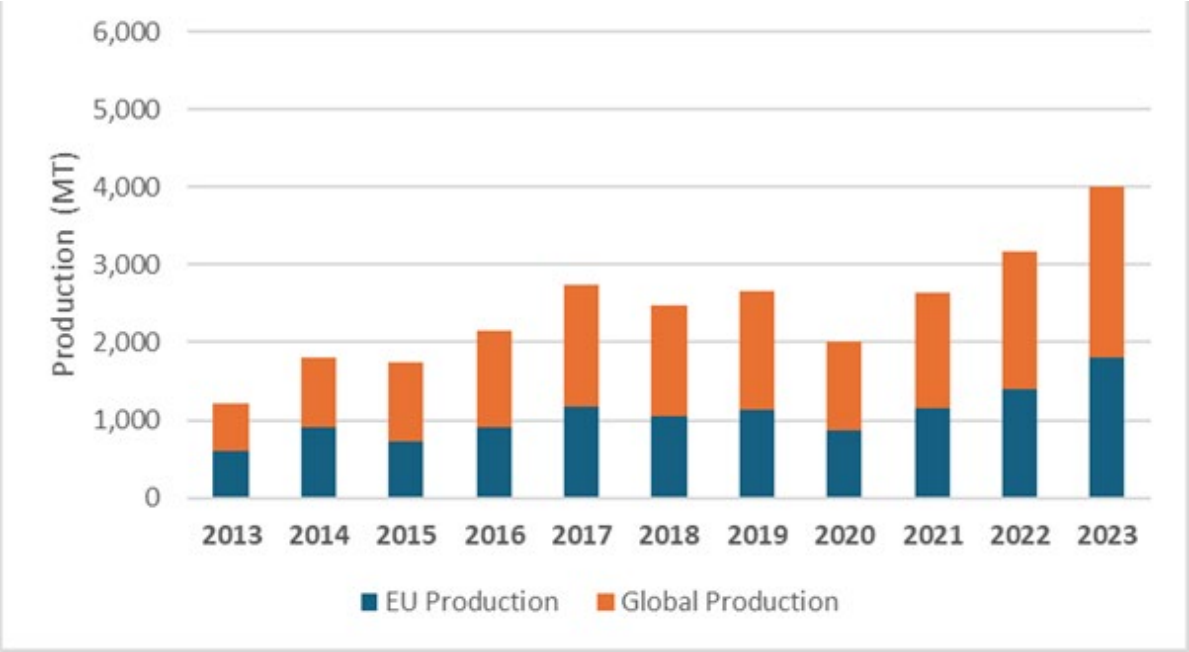


Figure 75 - Top EU sole producing countries in 2023

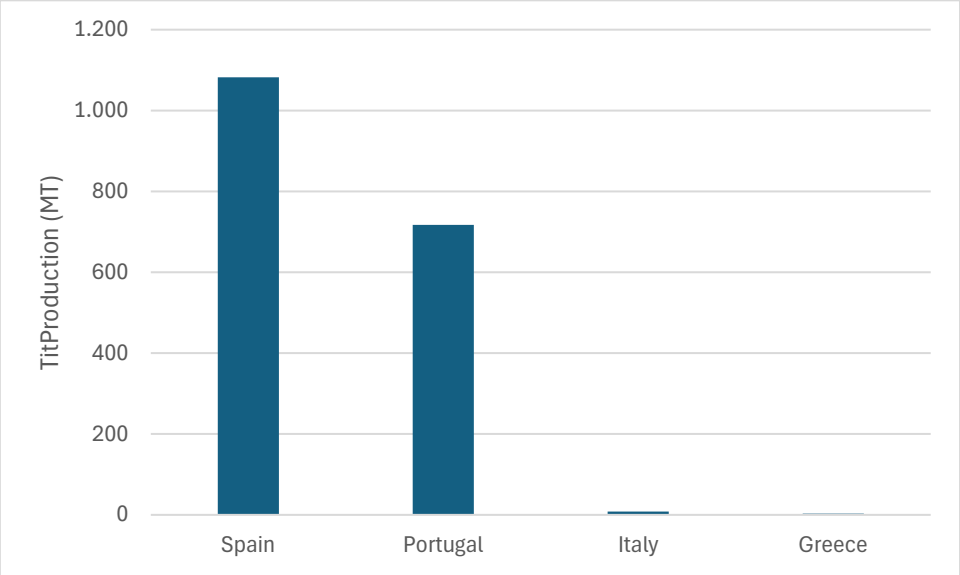


Figure 76 - Top sole producing countries globally in 2023

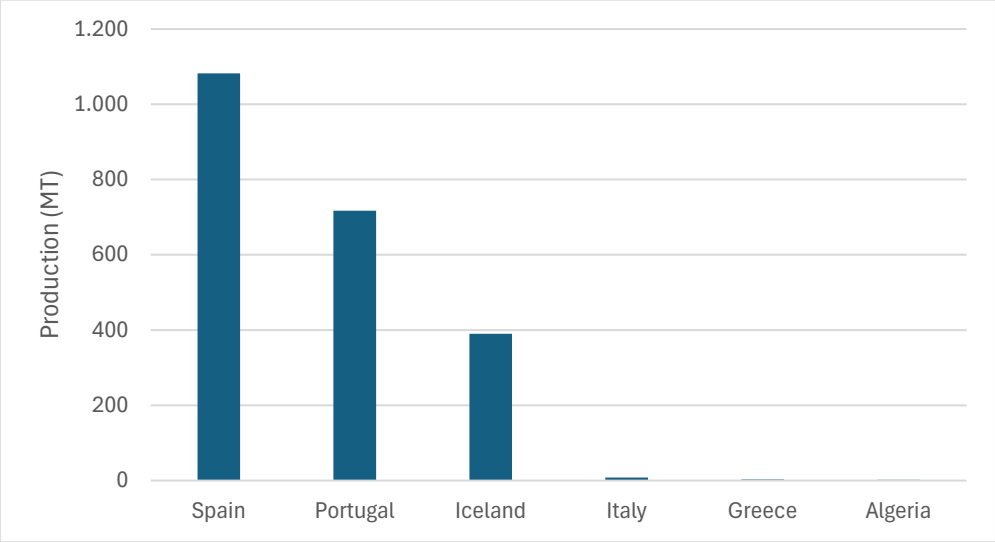


Figure 77 - Sole global production value and average fish price per kilo over a ten-year period

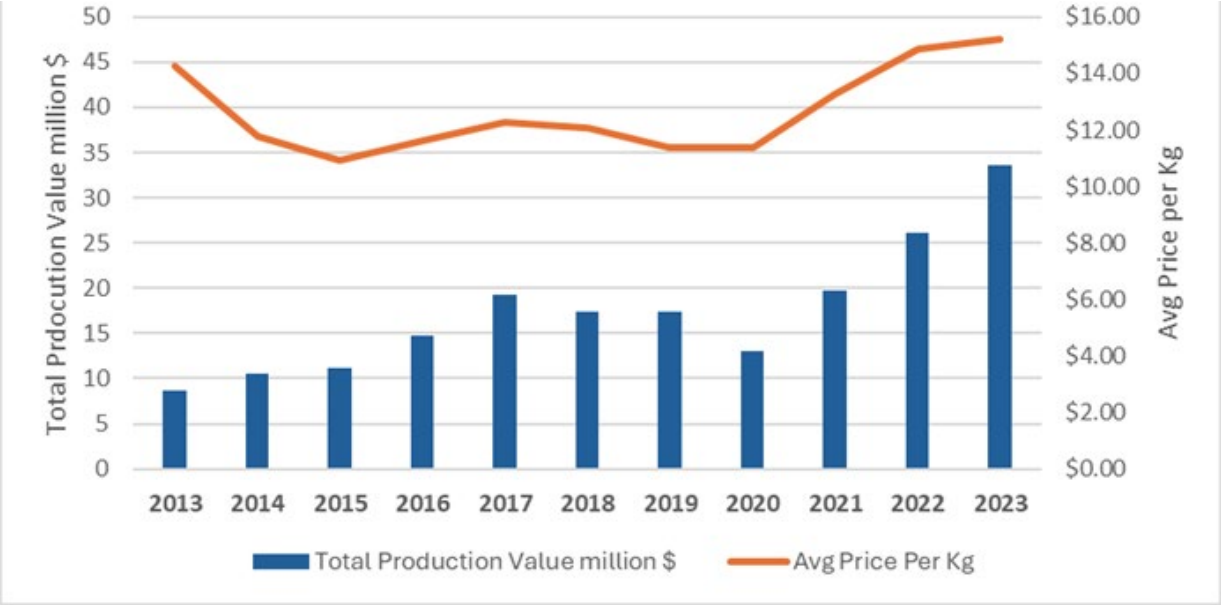


Table 65 - Production of sole species 2013-2023

Country	Species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Greece	Common sole	4	3	2	2	1	2	3	2	2	1	3
Italy	Common sole	9	7	7	5	5	8	5	9	8	0	8
Portugal	Common sole	154	84	130	4	5	145	1	1	0	0	0
Portugal	Senegalese sole	0	0	0	143	145	0	189	151	174	213	717
Spain	Common sole	0	0	9	0	0	0	0	0	0	0	0
Spain	Senegalese sole	440	806	582	747	1,013	893	945	705	962	1,192	1,082
Total Species Production		607	900	730	901	1,169	1,047	1,143	867	1,147	1,405	1,809
Global Species Production		607	900	1,020	1,261	1,569	1,438	1,521	1,141	1,486	1,759	2,201

9.9.3. FCR and feed costs calculation

A review of experimental trials on sole juveniles indicated that FCR values typically ranged around 1.0 and 1.2 (Rueda-Jasso et al. 2004; Rema et al. 2008; Borges et al. 2009; Silva et al. 2009). Pereira et al. (2019) reported an FCR of 1.6 up to a body weight of 60 g and 1.9 until the fish reach 150g. Cabral et al. (2013) observed and FCR of 1.48 during a 140 day feeding trial with on-growing Senegalese soles with an initial body weight of 105 g to a final body weight of 210 g. Similar results were found in the study of Reis et al. (2014) were soles with an average weight of 150g were reared in experimental conditions for 140 days with an FCR of 1.42. In a longer-term study, Valente et al. (2011) reported an FCR of 2.01 during an 8-month trial with a starting weight of 180 g and a final market size weight of 355 g. For the purposes of this study we assume an average FCR = 1.6 based on the data. Similarly, the juvenile FCR of 1.7 was taken from the average values of trials of Bonvini et al. (2015).

The Hellenic Aquaculture Producers Organisation (HAPO, 2024) provide average feed prices per year, which were used in the calculation of estimated value of feed.

9.9.4. Diet composition

Table 66 – Typical diet material composition of sole

Raw Material Category	Larvae Materials	Juvenile - Grower Materials
Vegetable protein sources	Maze gluten, Wheat gluten and Soy protein Concentrate	Soya meal, Sunflower cake/expeller, Maze gluten, Soy protein concentrate, Rapeseed meal, Lupin meal and Faba beans
Vegetable oils	Refined palm oil	Rapeseed oil, Soybean oil and Camelina oil
Carbohydrate sources	Wheat starch, Wheat Flour	Wheat Flour, Dry Distillers Grains with Solubles (DDGS)
Marine protein sources	Fish meal, Krill meal, Squid meal and Hydrolyzed fish protein	Fish meal, Krill meal, Squid meal and Hydrolyzed fish protein
Land protein sources	Blood meal and Whey protein	Blood meal, Hydrolyzed feather meal, Poultry meal, Hemoglobin powder and Whey protein
Land oil sources	-	Poultry oil
Single cell proteins	Dried algae (*Haematococcus pluvialis, Schizochytrium limacinum*), brewers yeast (*Saccharomyces cerevisiae*).	Dried algae (*Haematococcus pluvialis, Schizochytrium limacinum*), brewers yeast

Raw Material Category	Larvae Materials	Juvenile - Grower Materials
Marine oils	Fish oil and Algal oil	Fish oil and Algal oil
Micro materials (Antioxidants, Preservatives, Additives, Minerals, Vitamins, Probiotics)	Antioxidants (BHA, BHT, Propyl gallate and Citric acid)	Antioxidants (BHA, BHT, Propyl gallate and Citric acid)
	Preservatives (Sorbic acid, Calcium propionate, Orthophosphoric acid and Sodium Propionate)	Preservatives (Sorbic acid, Calcium propionate, Orthophosphoric acid)
	Additives (Herb extracts, Fish gelatin, Lecithin, Phospholipids)	Additives (Herb extracts, Fish gelatin, Betaine, Lecithin, Phospholipids)
	Vitamins (A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, Choline chloride)	Vitamins (A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, Choline chloride, Inositol)
	Minerals (Phosphorus, Calcium, Iron, Iodine, Copper, Manganese, Selenium and Zinc)	Minerals (Phosphorus, Calcium, Iron, Iodine, Copper, Manganese, Selenium and Zinc)
	Amino acids (Methionine)	Amino acids (Lysine, Methionine and Threonine)
	Probiotics (*Pediococcus acidilactici*)	Probiotics (*Pediococcus acidilactici*)

Table 67 - Feed demand of sole species (adults) 2013-2023 (EU)

Country	species	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Greece	Common sole	7	7	4	3	1	3	6	4	5	1	5
Italy	Common sole	18	14	14	10	10	15	10	17	17	0	15
Portugal	Common sole	308	168	260	9	11	290	2	2	0	0	0
Portugal	Senegalese sole	0	0	0	286	290	0	377	302	348	426	1,433
Spain	Common sole	0	0	19	0	0	0	0	0	0	0	0
Spain	Senegalese sole	880	1,611	1,164	1,494	2,025	1,787	1,890	1,409	1,924	2,383	2,164
Total Species Feed Demand		1,213	1,800	1,461	1,802	2,337	2,095	2,285	1,735	2,294	2,811	3,618
Global Species Feed Demand		1,213	1,800	2,041	2,522	3,137	2,877	3,043	2,281	2,972	3,519	4,402

Table 68 - Feed demand of juvenile sole (*S. senegalens*) 2014-2023 (EU)

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Rotifers Min (billion)	145	187	172	165	166	119	149	198	245	314
Rotifers Max (billion)	213	274	252	242	243	174	219	291	360	460
Enrichment Rotifers Min (L)	87	112	103	99	100	71	90	119	147	188
Enrichment Rotifers Max (L)	213	274	252	242	243	174	219	291	360	460
Artemia small (Kg cysts) -not enriched (Min)	19	25	23	22	22	16	20	26	33	42
Artemia small (Kg cysts) -not enriched (Max)	48	62	57	55	55	40	50	66	82	105
Artemia large enriched (kg cysts) (Min)	1,405	1,807	1,659	1,594	1,604	1,148	1,444	1,917	2,370	3,035
Artemia large enriched (kg cysts) (Max)	1,696	2,181	2,002	1,923	1,936	1,386	1,742	2,314	2,860	3,663
Enrichment Artemia products (L)(Min)	422	542	498	478	481	344	433	575	711	910
Enrichment Artemia products (L) (Max)	678	872	801	769	774	554	697	925	1,144	1,465
Co-feeding (200-300 µm) Kg compound diet Min	388	498	458	440	442	317	398	529	654	837

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Co-feeding (200-300 µm) Kg compound diet Max	581	748	686	659	664	475	597	793	981	1,256
Weaning (300-600 µm)Kg compound diet Min	2,423	3,115	2,860	2,748	2,765	1,980	2,489	3,305	4,086	5,232
Weaning (300-600 µm)Kg compound diet Max	3,392	4,361	4,004	3,847	3,871	2,772	3,485	4,627	5,720	7,325
Nursery (0,5-1,1mm or 0,3-3gr fish) Kg compound diet Min	19,477	25,045	22,994	22,090	22,231	15,917	20,012	26,574	32,852	42,067
Nursery (0,5-1,1mm or 0,3-3gr fish)Kg compound diet Max	20,252	26,041	23,910	22,969	23,115	16,551	20,808	27,631	34,159	43,741
Broodstock feeds Min Kg compound diet	775	997	915	879	885	634	796	1,058	1,308	1,674
Broodstock feeds Max Kg compound diet	1,163	1,495	1,373	1,319	1,327	950	1,195	1,586	1,961	2,511

Table 69 - Feed demand of juvenile sole (*S. senegalese)* 2014-2023 (Global)

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Rotifers Min (billion)	1,163	1,495	1,373	1,319	1,327	950	1,573	2,057	2,453	3,056
Rotifers Max (billion)	145	187	172	165	166	119	197	257	307	382
Enrichment Rotifers Min (L)	213	274	252	242	243	174	288	377	450	560
Enrichment Rotifers Max (L)	87	112	103	99	100	71	118	154	184	229
Artemia small (Kg cysts) -not enriched (Min)	213	274	252	242	243	174	288	377	450	560
Artemia small (Kg cysts) -not enriched (Max)	19	25	23	22	22	16	26	34	41	51
Artemia large enriched (kg cysts) (Min)	48	62	57	55	55	40	66	86	102	127
Artemia large enriched (kg cysts) (Max)	1,405	1,807	1,659	1,594	1,604	1,148	1,901	2,486	2,964	3,693
Enrichment Artemia products (L)(Min)	1,696	2,181	2,002	1,923	1,936	1,386	2,294	3,000	3,577	4,457

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Enrichment Artemia products (L) (Max)	422	542	498	478	481	344	570	746	889	1,108
Co-feeding (200-300 µm) Kg compound diet Min	678	872	801	769	774	554	918	1,200	1,431	1,783
Co-feeding (200-300 µm) Kg compound diet Max	388	498	458	440	442	317	524	686	818	1,019
Weaning (300-600 µm)Kg compound diet Min	581	748	686	659	664	475	787	1,029	1,226	1,528
Weaning (300-600 µm)Kg compound diet Max	2,423	3,115	2,860	2,748	2,765	1,980	3,277	4,285	5,110	6,367
Nursery (0,5-1,1mm or 0,3-3gr fish) Kg compound diet Min	3,392	4,361	4,004	3,847	3,871	2,772	4,588	6,000	7,154	8,913
Nursery (0,5-1,1mm or 0,3-3gr fish)Kg compound diet Max	19,477	25,045	22,994	22,090	22,231	15,917	26,350	34,455	41,084	51,188
Broodstock feeds Min Kg compound diet	20,252	26,041	23,910	22,969	23,115	16,551	27,399	35,827	42,719	53,225
Broodstock feeds Max Kg compound diet	775	997	915	879	885	634	1,049	1,371	1,635	2,037

Table 70 - Feed demand of juvenile sole (*S. solea*) 2014-2023 (EU)

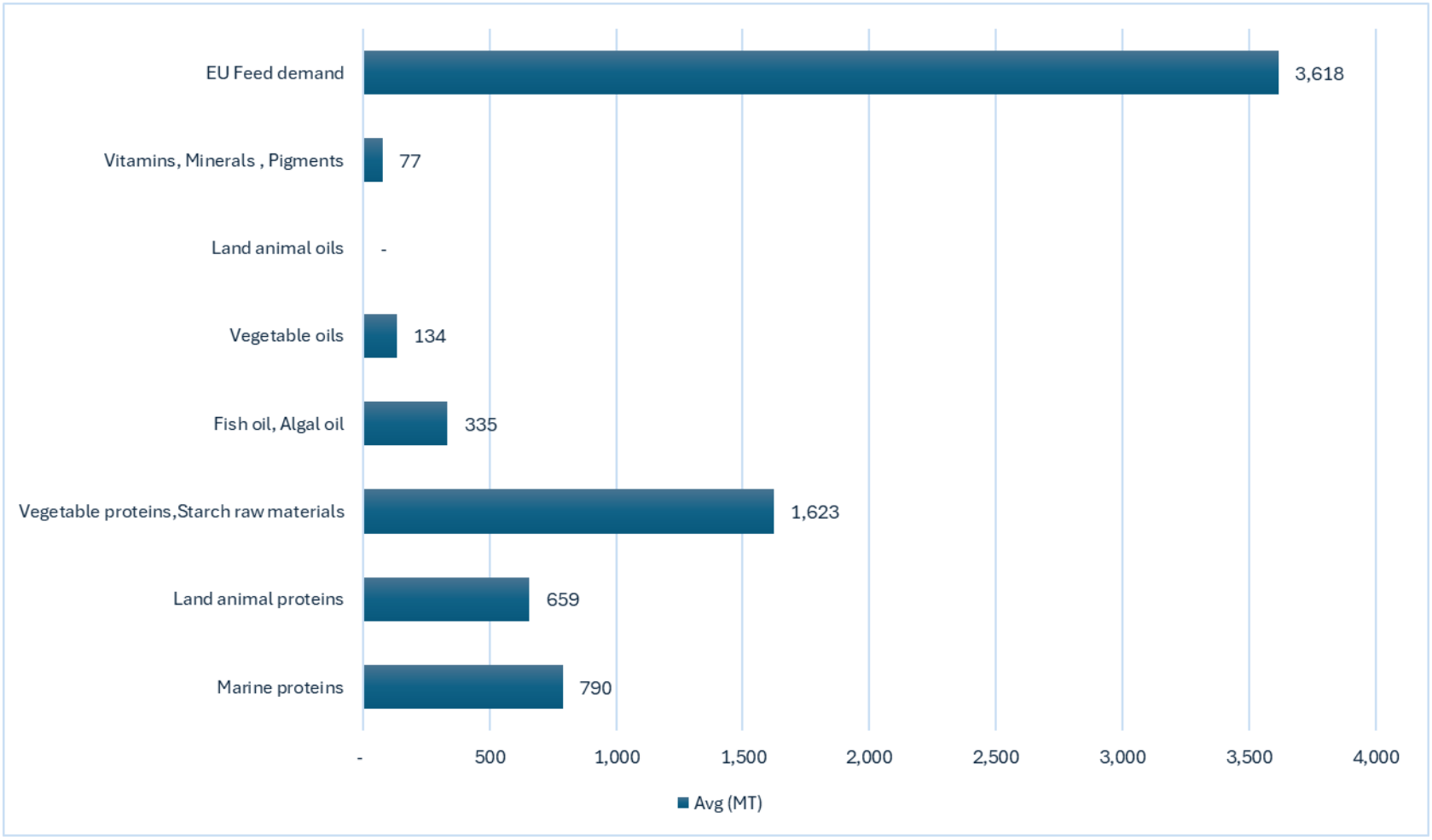
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Rotifers Min (billion)	16.80	13.80	1.37	1.39	19.41	1.13	1.47	1.36	0.08	1.29
Rotifers Max (billion)	24.64	20.24	2.01	2.05	28.47	1.65	2.16	2.00	0.11	1.89
Enrichment Rotifers Min (L)	10.1	8.3	0.8	0.8	11.6	0.7	0.9	0.8	0.0	0.8
Enrichment Rotifers Max (L)	24.6	20.2	2.0	2.0	28.5	1.7	2.2	2.0	0.1	1.9
Artemia small (Kg cysts) -not enriched (Min)	2.2	1.8	0.2	0.2	2.6	0.2	0.2	0.2	0.0	0.2
Artemia small (Kg cysts) -not enriched (Max)	5.6	4.6	0.5	0.5	6.5	0.4	0.5	0.5	0.0	0.4

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Artemia large enriched (kg cysts) (Min)	162.4	133.4	13.3	13.5	187.6	10.9	14.2	13.2	0.8	12.5
Artemia large enriched (kg cysts) (Max)	196.0	161.0	16.0	16.3	226.4	13.2	17.2	15.9	0.9	15.1
Enrichment Artemia products (L)(Min)	48.7	40.0	4.0	4.0	56.3	3.3	4.3	3.9	0.2	3.7
Enrichment Artemia products (L) (Max)	78.4	64.4	6.4	6.5	90.6	5.3	6.9	6.3	0.4	6.0
Co-feeding (200-300 µm) Kg compound diet Min	44.8	36.8	3.7	3.7	51.8	3.0	3.9	3.6	0.2	3.4
Co-feeding (200-300 µm) Kg compound diet Max	67.2	55.2	5.5	5.6	77.6	4.5	5.9	5.4	0.3	5.2
Weaning (300-600 µm) Kg compound diet Min	280.0	230.0	22.9	23.2	323.5	18.8	24.5	22.7	1.3	21.5
Weaning (300-600 µm) Kg compound diet Max	392.0	322.0	32.0	32.5	452.9	26.3	34.4	31.7	1.8	30.1
Nursery (0,5-1,1mm or 0,3-3gr fish) Kg compound diet Min	2,251.2	1,849.2	183.8	186.9	2,600.9	151.1	197.4	182.3	10.5	173.0
Nursery (0,5-1,1mm or 0,3-3gr fish) Kg compounddiet Maxx	2,340.8	1,922.8	191.2	194.3	2,704.4	157.1	205.2	189.6	10.9	179.9
Broodstock feeds Min Kg compound diet	89.6	73.6	7.3	7.4	103.5	6.0	7.9	7.3	0.4	6.9
Broodstock feeds Max Kg compound diet	134.4	110.4	11.0	11.2	155.3	9.0	11.8	10.9	0.6	10.3

Table 71 - Feed demand of juvenile sole (*S. solea*) 2014-2023 (EU)

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Rotifers Min (billion)	16.8	13.8	1.4	1.4	19.4	1.3	1.7	1.6	0.3	1.5
Rotifers Max (billion)	24.6	20.2	2.0	2.0	28.5	2.0	2.6	2.4	0.5	2.3
Enrichment Rotifers Min (L)	10.1	8.3	0.8	0.8	11.6	0.8	1.0	1.0	0.2	0.9
Enrichment Rotifers Max (L)	24.6	20.2	2.0	2.0	28.5	2.0	2.6	2.4	0.5	2.3
Artemia small (Kg cysts) -not enriched (Min)	2.2	1.8	0.2	0.2	2.6	0.2	0.2	0.2	0.0	0.2
Artemia small (Kg cysts) -not enriched (Max)	5.6	4.6	0.5	0.5	6.5	0.4	0.6	0.5	0.1	0.5
Artemia large enriched (kg cysts) (Min)	162.4	133.4	13.3	13.5	187.6	13.0	16.9	15.8	3.2	14.9
Artemia large enriched (kg cysts) (Max)	196.0	161.0	16.0	16.3	226.4	15.7	20.4	19.1	3.9	18.0
Enrichment Artemia products (L)(Min)	48.7	40.0	4.0	4.0	56.3	3.9	5.1	4.7	1.0	4.5
Enrichment Artemia products (L) (Max)	78.4	64.4	6.4	6.5	90.6	6.3	8.2	7.6	1.5	7.2
Co-feeding (200-300 µm) Kg compound diet Min	44.8	36.8	3.7	3.7	51.8	3.6	4.7	4.4	0.9	4.1
Co-feeding (200-300 µm) Kg compound diet Max	67.2	55.2	5.5	5.6	77.6	5.4	7.0	6.6	1.3	6.2
Weaning (300-600 µm) Kg compound diet Min	280.0	230.0	22.9	23.2	323.5	22.5	29.2	27.3	5.5	25.7
Weaning (300-600 µm) Kg compound diet Max	392.0	322.0	32.0	32.5	452.9	31.5	40.8	38.2	7.7	36.0
Nursery (0,5-1,1mm or 0,3-3gr fish) Kg compound diet Min	2,251.2	1,849.2	183.8	186.9	2,600.9	180.8	234.5	219.5	44.2	206.8
Nursery (0,5-1,1mm or 0,3-3gr fish) Kg compound diet Max	2,340.8	1,922.8	191.2	194.3	2,704.4	188.0	243.8	228.2	46.0	215.0
Broodstock feeds Min Kg compound diet	89.6	73.6	7.3	7.4	103.5	7.2	9.3	8.7	1.8	8.2
Broodstock feeds Max Kg compound diet	134.4	110.4	11.0	11.2	155.3	10.8	14.0	13.1	2.6	12.3

Figure 78 - Estimated EU feed material demand for sole (tonnes) (2023)



9.10. Sturgeon

9.10.1. Life history

Sturgeon aquaculture practices vary, but common technologies include indoor recirculating aquaculture systems (RAS) for controlled environments and traditional flow-through or pond systems in open areas. The choice of system affects growth rates, product quality, and environmental impact. Advanced breeding techniques, such as hormonal induction for spawning, and selective breeding programs using captive-bred broodstock, are employed to optimize productivity and maintain genetic diversity (EUMOFA, 2023b). Despite technological advances, sturgeon farming remains a capital-intensive activity, requiring significant investment in infrastructure and long-term stock management.

Possessing a unique digestive system, sturgeon generally utilizes energy derived from lipids more efficiently than from carbohydrates and requires a moderate to high level of protein in the diet. A balanced supply of essential fatty acids is crucial for the production of high-quality caviar, while a well-defined content of essential amino acids is necessary for the production of high-quality sturgeon meat.

Overall, sturgeon aquaculture is an important and growing segment of the global and EU aquaculture sectors, with the EU contributing a small but significant share of global production. The production of sturgeon meat is essential for the economic viability of sturgeon farms, as it helps offset the long production cycles and high costs associated with caviar production (EUMOFA, 2023b).

9.10.2. Production, production trends and statistics

Sturgeon farming has developed significantly over the past two decades, primarily to support the production of caviar, but also for sturgeon meat, which represents an important “by-product” for caviar production-oriented aquaculture. Global sturgeon aquaculture production has experienced substantial growth, with production increasing from approximately 4,100 tonnes in 2002 to an estimated 123,476 tonnes in 2020. This expansion has been largely driven by China, which accounted for 84% of global production in 2020. Russia and Armenia followed, contributing 4% (4,836 tonnes) and 3% (4,200 tonnes) respectively (EUMOFA, 2023b). This concentration of production in a few countries highlights the global reliance on a limited number of major producers for both caviar and sturgeon meat.

Within the EU, Italy has been the leading producer of sturgeon, followed by Poland and Bulgaria. In 2020, Italy produced 1,051 tonnes of sturgeon, predominantly white sturgeon *(Acipenser transmontanus),* Danube sturgeon *(Acipenser gueldenstaedtii)*, and Siberian sturgeon *(Acipenser baerii)*. Poland and Bulgaria focused primarily on Siberian and Danube sturgeon, while France produced mainly Siberian sturgeon (EUMOFA, 2023b). The EU aquaculture sector employs a variety of production systems, with flow-through systems being the most common (36% of production), followed by recirculating aquaculture systems (RAS; 21%) and open net pens (18%). Ponds and mixed systems account for the remainder of production (EUMOFA, 2023b).

Sturgeon production in the European Union, particularly in leading producing countries such as Italy, Poland, and Bulgaria, is primarily oriented toward caviar production. The volume of sturgeon sold does not fully reflect the actual biomass growth in a given year, as the production cycle is long and largely driven by the needs of the caviar market.

Sturgeon farming is characterized by long production cycles due to the species' biological characteristics. It takes between 8 to 10 years for female sturgeons to reach sexual maturity and begin caviar production. In the initial years, both male and female sturgeons are reared together until sex differentiation is possible through methods such as ultrasound and biopsy. Males are typically harvested for meat once identified, while females are retained for caviar production, making sturgeon meat an important co-product. It is estimated that approximately 20 tonnes of sturgeon meat are produced for every tonne of caviar harvested (EUMOFA, 2023b).

Based on our own estimates, the current biomass multiplication factor in sturgeon farming — defined as the ratio between total sturgeon actual biomass and current caviar production — is approximately 95:1.

Figure 79 - Global production volume and value of sturgeon (*Acipenser spp.* and *Huso spp*)

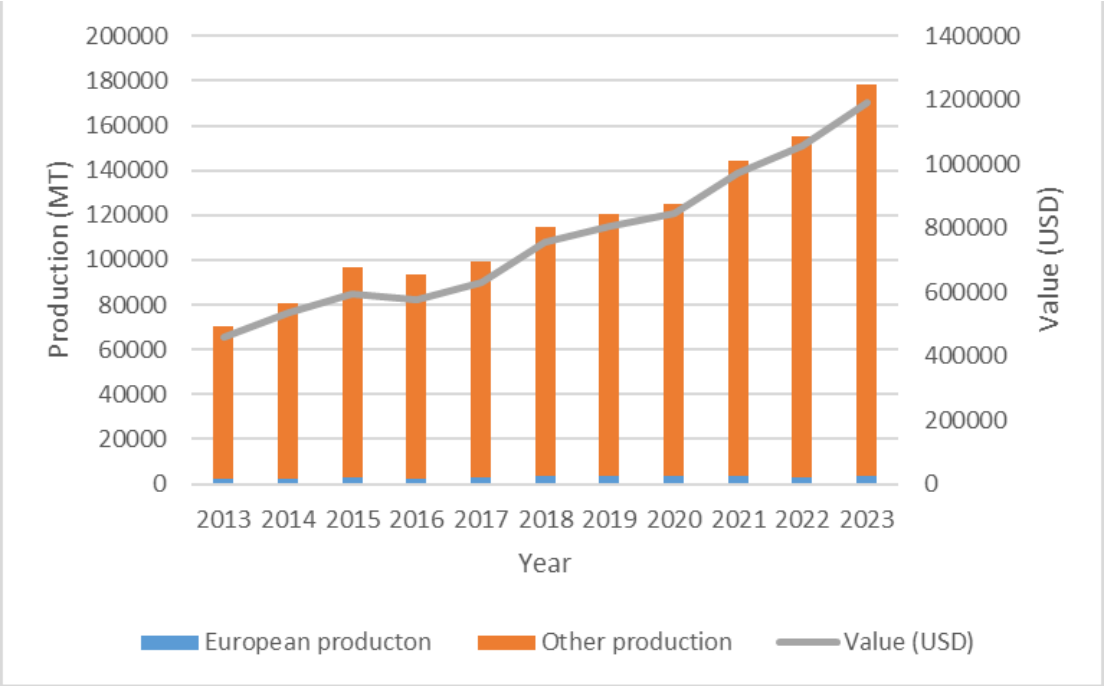


Table 72 – Production (tonnes) of sturgeons (production from aquaculture excluding hatcheries and nurseries)

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Global Production	80,946	96,735	93,425	99,020	114,731	120,544	125,060	144,166	154,937	178,577
EU-27	2 226	2 464	2 483	4 062	2 992	3 159	3 146	3 342	2 901	3 071
Bulgaria	247	336	303	156	279	233	175	268	196	247
Denmark	1	4	0					2	2	2
Germany	257	222	185	183	160	161	149	148	131	109
Estonia		57	16	19	18				13	27
Greece			0	31	13	13	12	0	0	140
Spain	33	36	54	72	103	111	160	138	40	66
France	402	445	258	321	289	289	404	245	249	4
Croatia					1	1	0	0		
Italy	824	803	920	2040	1179	1301	1125	1253	950	1098
Cyprus	1	3	1	1	3	4	3	4	5	1
Latvia			51			45	38	55	46	
Lithuania	73	83	118	117	153	165	95	154	197	126
Hungary	48	142	76	97	69	65	7	71	124	156
Austria	3	4	8	11	14	15	12	13	15	17
Poland	329	317	459	764	659	664	879	852	756	853
Portugal										
Romania	8	14	35	252	53	93	84	137	177	225
Slovenia							3	2	0	0

Data source: Eurostat Aquaculture production by species. (2025)

Table 73 – EU production (tonnes) of sturgeons’ eggs for human consumption (caviar)

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU-27 countries	59.2	70.5	86.4	93.4	109.0	136.4	122.2	160.7	147.5	153.2
Bulgaria						0.5	0.6	9.9	1.6	1.4
Denmark			0.0	0.0	0.0	0.1	0.1	0.2		
Estonia						0.0	0.0			
Spain	1.6	1.5	1.2	1.4	1.3	1.2	1.0	1.4	0.9	3.1
France	21.1	21.8	29.0	36.8	39.9	43.5	44.1	44.0	49.9	44.6
Italy	34.7	35.8	39.3	34.7	48.7	61.7	55.3	62.6	62.0	65.0
Cyprus					0.1	0.1	0.1			
Hungary			0.5	1.0		0.0	0.1	0.0	0.0	0.0
Poland	1.9	11.4	16.4	19.5	19.0	29.3	20.9	42.4	32.6	39.1
Romania								0.2	0.5	

Data source: Eurostat Aquaculture production by species. (2025)

Table 74 – EU production (million) of sturgeons at juvenile stage

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU-27	1.184	2.163	2.017	0.971	1.754	1.721	3.194	2.070	2.977	1.656
Bulgaria	0.100	0.230	0.520	0.033	0.043	0.140	0.269	0.006		0.010
Czechia								0.600	0.600	
Germany		0.270								
Estonia						0.005	0.002	0.011	0.001	
Spain						0.003		0.000		
France		0.300								
Italy	0.040	0.110	0.120	0.042	0.140	0.134	0.101	0.086	0.090	0.090
Cyprus	0.010						0.007	0.003	0.002	
Latvia	0.040			0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lithuania	0.004	0.003	0.007	0.017	0.006	0.031	0.039	0.063	0.056	0.155
Hungary	0.260	0.130	0.200	0.110	0.210	0.223	0.874	0.069	0.182	0.096
Poland	0.730	1.100	1.120	0.769	1.232	1.185	1.863	1.232	2.013	1.256
Romania		0.020	0.050		0.124		0.038		0.032	0.050

Data source: Eurostat Aquaculture production by species. (2025)

9.10.1. FCR, feed demand feed cost calculation

While the scientific literature reports numerous experimental studies indicating very low feed conversion ratio (FCR) values for sturgeon — from as low as 0.66 or 0.71 in specific controlled conditions (Pěnka *et al* 2024), up to 0.90 (Wnęk-Auguścik *et al* 2024) — practical, commercial-scale sturgeon farming operations report higher FCR values in real-world settings. For example, FCRs reported by commercial feed suppliers for sturgeon range from approximately 1.0 (Aller Aqua, 2024) to 1.6 (Szramek, 2025). In this context, it is reasonable and safe to estimate a feed conversion of 1.3 kg of feed per 1.0 kg of biomass growth in European sturgeon aquaculture. For juvenile fish, a value of 1.7 was found in two separate trials on *A. baerii* (Köksal et al, 2000 and Shirvan *et al,* 2020).

Two sturgeon food manufactures were used to estimate the cost of sturgeon food (Aller Aqua, n.d; Faradaneh, 2023). The former is from a supplier which distributes in 25 kg bags (Amazon, 2025) which likely inflates the price for small volumes, and the latter is the average from a range of 13 sturgeon diets made by the supplier. An overall average from both manufacturers provides a cost of EUR 1,821/t.

9.10.2. Diet composition

Table 75 – Typical diet composition of sturgeon feed

Material	Source
Vegetable protein sources	Plant proteins
Vegetable oils	Vegetable oils
Carbohydrate sources	Cereal products
Marine protein sources	Fish meal
	Krill meal
	Marine by-products
Land protein sources	Single-cell proteins
	Blood meal
	Non-marine by-products
	Processed animal proteins
Marine oils	Fish oil
Land based oils	Processed animal oils
Micro materials	Functional additives
	Vitamins and minerals

Table 76 – Feed demand (tonnes) sturgeon juveniles* 2014-2023

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU total	63.6	116.2	108.4	52.2	94.2	92.5	171.6	111.2	159.9	89.0
Bulgaria	5.4	12.4	27.9	1.8	2.3	7.5	14.5	0.3		0.5
Czechia								32.2	32.2	
Estonia						0.3	0.1	0.6	0.1	
Spain						0.2				
France		16.1								
Italy	2.1	5.9	6.4	2.3	7.5	7.2	5.4	4.6	4.8	4.8
Cyprus	0.5						0.4	0.2	0.1	
Latvia	2.1									
Lithuania	0.2	0.2	0.4	0.9	0.3	1.7	2.1	3.4	3.0	8.3
Hungary	14.0	7.0	10.7	5.9	11.3	12.0	47.0	3.7	9.8	5.2
Poland	39.2	59.1	60.2	41.3	66.2	63.7	100.1	66.2	108.1	67.5
Romania		1.1	2.7		6.7		2.0		1.7	2.7

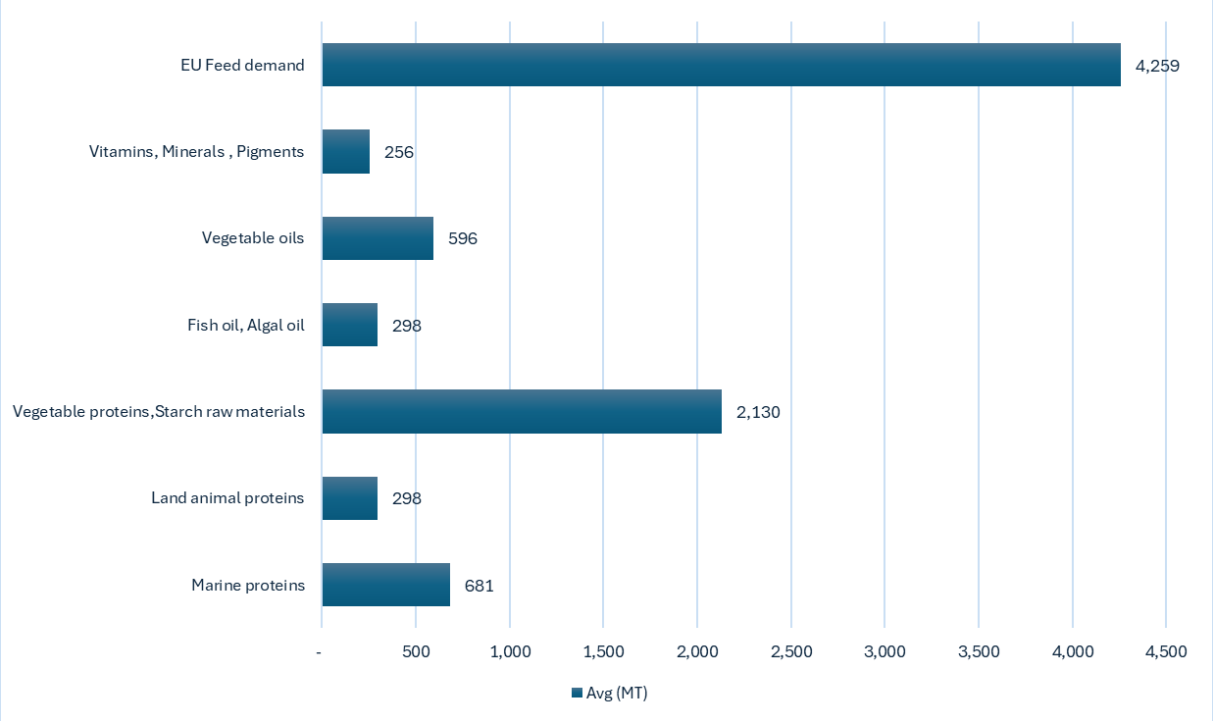
* Based on juvenile size of 31.6g (Köksal *et al*, 2000 and Shirvan *et al,* 2020).

Table 77 – Feed demand (tonnes) sturgeon 2014-2023

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Austria	3	3.6	7.8	10.5	14.2	14.9	12.15	13.38	15.27	3
Belgium	0	0	0	0	0	0	0	0	0	0
Bulgaria	261.6	331.43	296.61	262.44	429.66	260.63	290.03	273.35	182.21	261.6
Croatia	0	0	0	0	0.83	0.74	0.66	0	0	0
Cyprus	1.2	3	0.7	0.61	2.84	4	2.6	4	4.8	1.2
Denmark	1	4	3	3	3	0	1	1.8	1.7	1
Estonia	0	56.5	16.1	19	18.14	41.4	50.26	14.57	13.31	0
France	402.3	445	257.5	320.74	409	288.68	404.41	244.69	331.2	402.3
Germany	257	222	185	183	160	161	149	148	131	257
Greece	42.8	0	0	0	12.7	12.66	12.41	12	12	42.8
Hungary	48	142	76	97.2	68.7	87.39	67.49	70.73	123.97	48
Italy	823.81	850	1000	1000	1178.92	1300	1050.6	1252.6	950	823.81

Country	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Latvia	54.07	91.3	51.45	42.3	40.38	22.39	38.44	55.43	45.8	54.07
Lithuania	72.82	90.6	126.59	120.47	155.16	165.61	85.39	154.53	190.91	72.82
Netherlands (Kingdom of the)	40	50	50	100	150	150	150	150	150	40
Poland	472	316.7	459.15	763.63	659.04	664.4	879.31	852.31	756.14	472
Romania	0.92	12.51	33	251.88	50.84	94.43	84	146	177.43	0.92
Slovakia	0	0	0	1.05	0	0	0	0	0	0
EU27	3267	3441	3402	4222	4363	4439	4456	4572	4069	4272
Global	105230	125756	121452	128727	149150	156707	162577	187416	201419	232151

Figure 80 – Estimated EU feed material demand for sturgeon (tonnes) (2023)



9.11. Turbot

9.11.1. Life history

Turbot (*Scophthalmus maximus/Psetta maxima*) is a benthic marine species normally inhabiting sandy or muddy seabed. Although adults can live in waters as deep as 100 m, juveniles tend to live in shallower water (Seafish, 2025). It is known to inhabit the Black Sea, Mediterranean Sea, the Baltic Sea and the North Atlantic and a length of 1m and weight of 25 kg have been recorded (Adriaticnature, n.d.). In the wild, juveniles feed on molluscs and crustaceans and adults feed mainly on fish and cephalopods. Spawning usually takes place between the months of May and July in the Atlantic and between February and April in the Mediterranean Sea.

9.11.2. Production, production trends and statistics

In Europe, the aquaculture production of turbot started in the 1970s and expanded in Europe, to be taken up by Chile and China which is the main producer at this time (FAO, 2025c).

Figure 81 - Global production volume and value of turbot

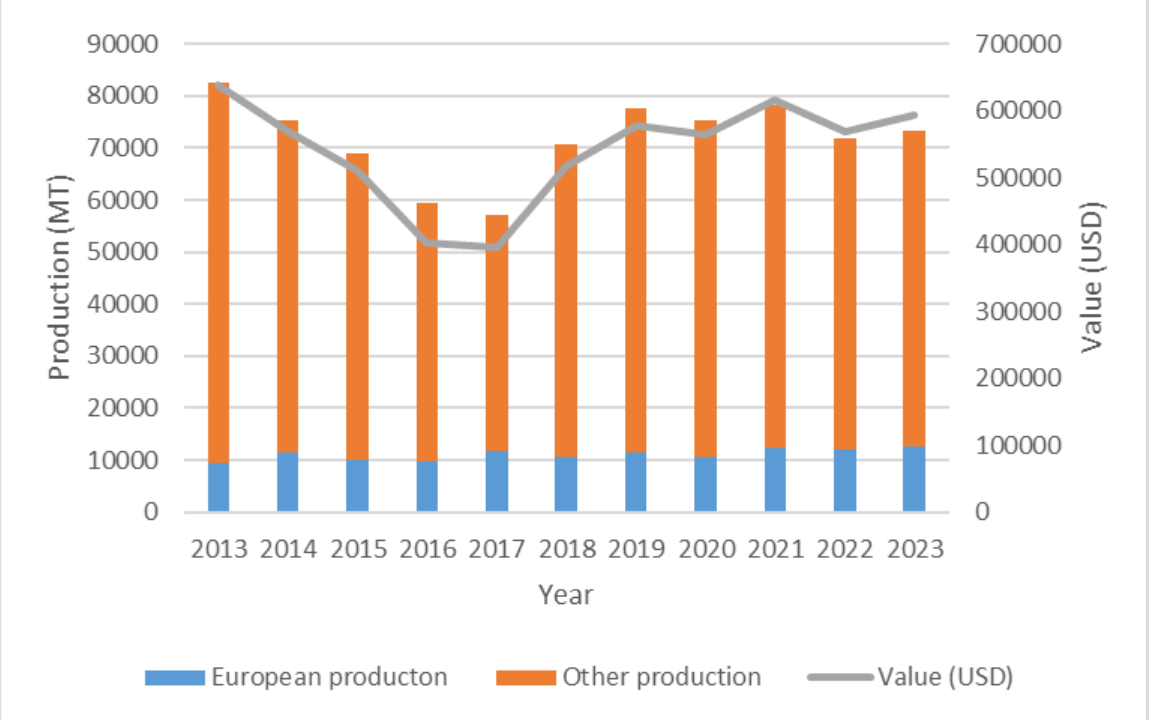


Table 78 – Global turbot production by country and total value

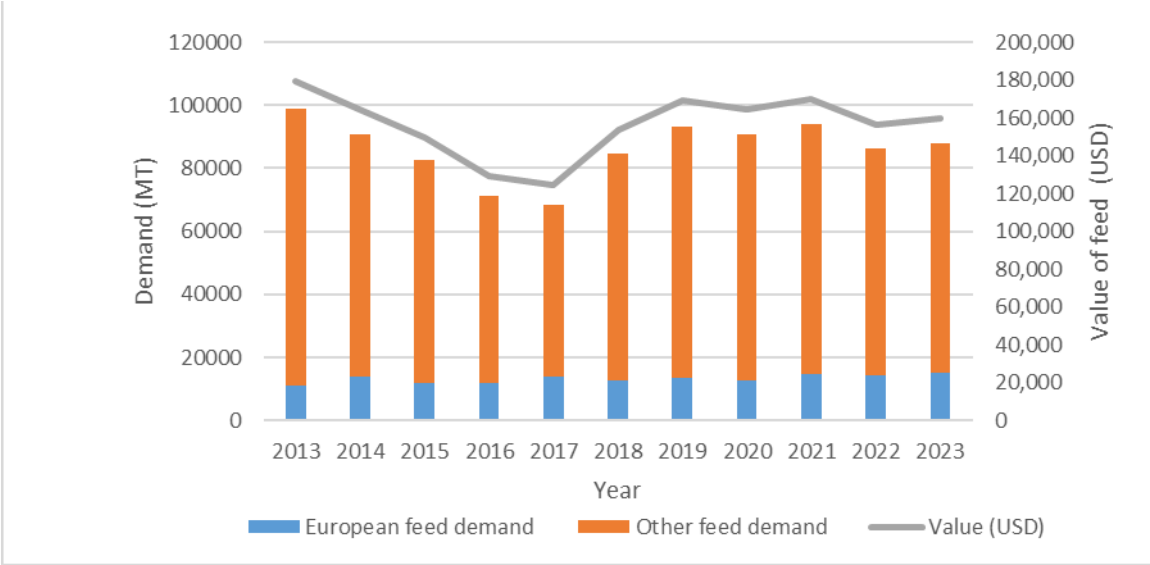
Country	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Chile	107	2	3	0	0	2	1	2	0	2	1
China	73,000	64,000	59,000	49,500	45,500	60,000	66,300	65,000	66,000	60,000	60,739
Croatia	0	1	7	1	0	0	0	0	0	0	0
Denmark	7	4	0	0	0	0	0	0	0	0	0
Iceland	58	0	0	0	0	0	0	0	0	0	0
Ireland	0	0	0	0	0	0	0	0	0	0	0
Italy	0	0	0	0	0	0	0	0	30	5	0
Jersey	1	0	0	0	0	0	0	0	0	0	0
Netherlands	100	100	100	100	100	100	100	100	100	100	0
Portugal	2,353	3,588	2,302	2,388	2,745	2,582	3,297	3,407	3,538	3,074	3,209
Romania	0	16	20	20	0	0	0	0	0	0	0
Spain	6,900	7,767	7,464	7,306	8,771	7,995	8,011	6,963	8,538	8,702	9,474
Total EU Production (tonnes)	9,360	11,475	9,893	9,816	11,617	10,677	11,409	10,470	12,206	11,881	12,683
Total Global Production (tonnes)	82526	75477	68896	59316	57117	70679	77710	75472	78206	71883	73423
EU % Market Share	11%	15%	14%	17%	20%	15%	15%	14%	16%	17%	17%
Global Production Value (USD)	639355	568878	510882	403302	396570	517123	578173	564717	616080	568779	594314

Table 79 – Hatchery production of turbot

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Total EU Production (kg)	9,360	11,475	9,893	9,816	11,617	10,677	11,409	10,470	12,206	11,881	12,683
Total Global Production (kg)	82526	75477	68896	59316	57117	70679	77710	75472	78206	71883	73423
Total EU Feed use (kg)	11232	13770	11871.6	11779.2	13940.4	12812.4	13690.8	12564	14647.2	14257.2	15219.6
Total Global Feed use (kg)	99031.2	90572.4	82675.2	71179.2	68540.4	84814.8	93252	90566.4	93847.2	86259.6	88107.6
EU Hatchery juvenile production (millions)	254.421[1]	22.61	26.44	8.47	14.1	11.78	11.315	112	11.62	12.985	11.856
Total Feed for EU Hatchery production (kg)	1448972	128854	150682	48271	80356	67134	64484	55726	62689	73999	67567

1. Hatchery production number provided by Eurostat for 2013 appears anomalous as it is a magnitude higher than the production in any of the following years.
2. Hatchery production number for 2020 not provided by Eurostat; an estimate based on production tonnage is given here.

Figure 82 - Global feed demand for turbot



9.11.1. FCR, feed demand and feed costs calculation

At hatchery stage, FCRs of 0.72-1.25 (average 0.95) have been reported (Aydin *et al,* 2011). During the grow out phase until harvest, an average FCR of 1.2 was applied (ranges indicated in the literature vary from 0.8 to 1.8 (Arnason *et al* 2009; FAO 2025e; Seafish, 2025).

The EC’s 2024 Aquaculture Economic Report (European Commission Joint Research Centre. & Scientific, Technical and Economic Committee for Fisheries., 2025) provides data showing feed costs of EU farmed species. Though not providing specific data for turbot, assumptions can be made. Production costs of sea bream and sea bass were 43% of the total costs of incurred, indicating an average cost of feed to be EUR 1,813/tonne. Production costs of turbot have been reported at a similar rate (42%) (Cang *et al;* 2018) so an equivalent price of food is assumed.

Like European seabass, meagre etc, turbot larvae are initial fed rotifers and Artemia and then weaned onto formulated diets. Prior to feeding to the larvae, an estimate of Artemia requirement was calculated based on the feeding regime indicated in FAO (2023). This determination is based on an initial stocking density of 30,000 larvae/m^3 (no change in tank size), a live feed stage survival of 12.5% (Pyanov, 2021), and a four times a day live feed check and full consumption of artemia in the larval tanks. Additionally, there are enrichments (rotifers and artemia) applied as per the instructions of the product chosen for use by the hatchery, which is calculated to be 14.9 kg/million juveniles and 180.8 kg/million juveniles for rotifers and artemia respectively (based on the recommendations of an important product used commercially) (see Annex I Section 6.11). Dry feed-based usage in hatcheries until the fish reach 6g in

weight was calculated using the recommended % daily feeding rates and survival indicated in FAO (2023).

9.11.2. Diet composition

Table 80 – Typical diet composition of turbot feed

Material	Source (juvenile)	Source (adult)
Vegetable protein sources	Wheat gluten	Wheat gluten
Vegetable oils		Rapeseed oil
Carbohydrate sources	Wheat meal	Wheat meal
	Pea starch	
Marine protein sources	Fish meal	Fish meal LT70
		Fish protein hydrolsate
		krill meal
		squid meal
Land protein sources	Soy protein concentrate	soy protein concentrate
	Soybean meal	single cell protein
Marine oils	Fish oil	Fish oil
		Micro-algae
Micro materials	Vit+Mins	Vit+Mins
	Antioxidant	Betaine HCl
	Sodium propionate	Antioxidant
		Sodium propionate
		Monoammonium phosphate
		yeast autolysate
		Phospholipids
Material	Source (juvenile)	Source (adult)
Vegetable protein sources	Wheat gluten	Wheat gluten
Vegetable oils		Rapeseed oil
Carbohydrate sources	Wheat meal	Wheat meal

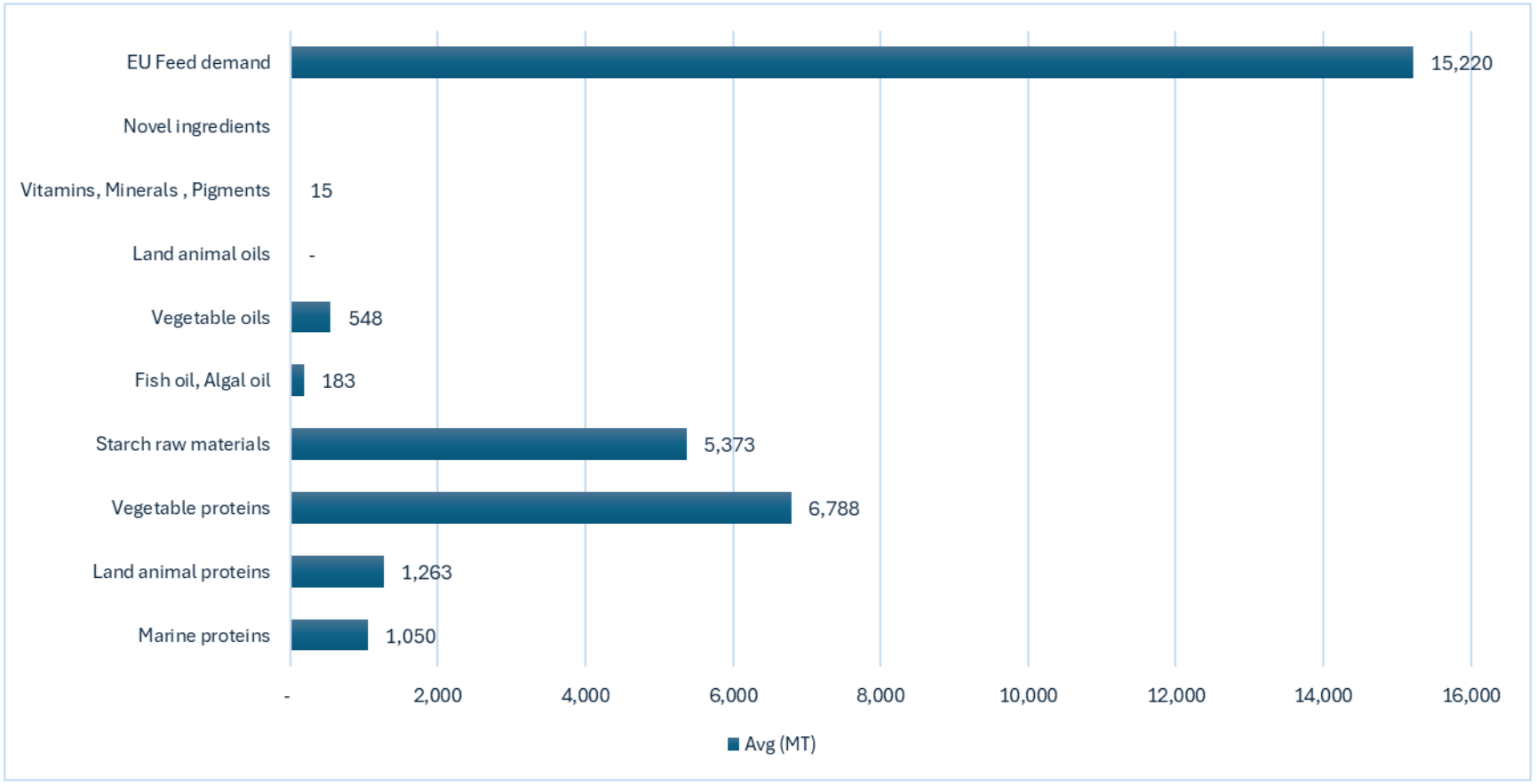
Table 81 – Artemia requirement (tonnes) and rotifer and artemia enrichment requirements (tonnes) for turbot hatchery production (millions) between 2014 and 2023

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU Hatchery juvenile production	22.61	26.44	8.47	14.1	11.78	11.32	11	11.62	12.99	11.86
Artemia requirement	9.47	11.08	3.55	5.91	4.94	4.74	4.61	4.87	5.44	4.97
Rotifer enrichment requirement	0.34	0.39	0.13	0.21	0.18	0.17	0.16	0.17	0.19	0.18
Artemia enrichment requirement	4.09	4.78	1.53	2.55	2.13	2.05	1.99	2.10	2.35	2.14

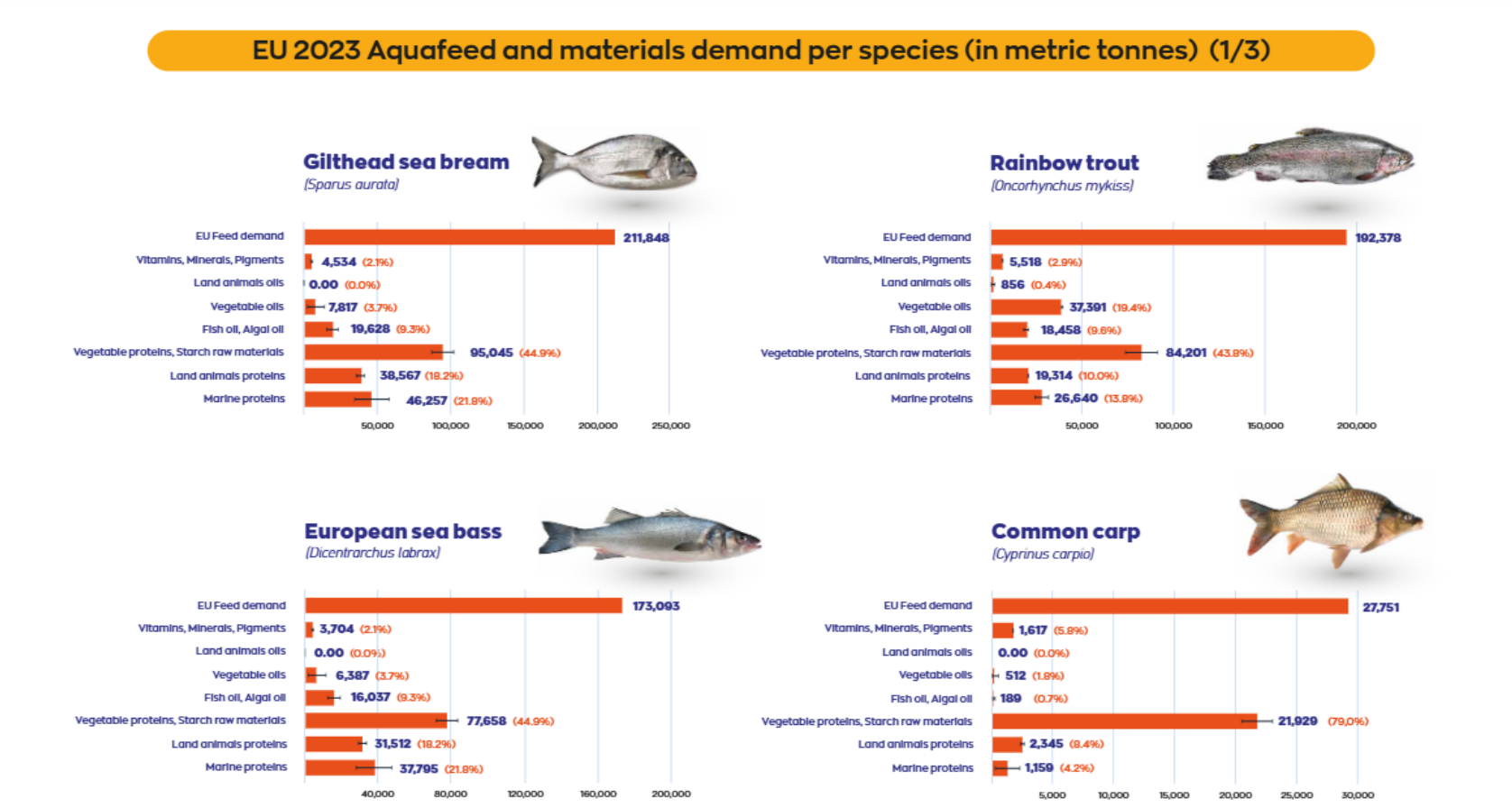
Table 82 – Aquafeed demand of turbot 2013-2023 in the EU

Country (Name)	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Croatia	0	1	9	1	0	0	0	0	0	0	0
Denmark	8	5	0	0	0	0	0	0	0	0	0
France	0	0	0	0	0	0	0	0	0	0	0
Germany	0	0	0	0	0	0	0	0	0	0	0
Ireland	0	0	0	0	0	0	0	0	0	0	0
Italy	0	0	0	0	0	0	0	0	36	6	0
Malta	0	0	0	0	0	0	0	0	0	0	0
Netherlands (Kingdom of the)	120	120	120	120	120	120	120	120	120	120	0
Portugal	2,824	4,305	2,762	2,866	3,294	3,098	3,957	4,088	4,246	3,689	3,851
Romania	0	19	24	24	0	0	0	0	0	0	0
Spain	8,280	9,320	8,957	8,768	10,526	9,594	9,614	8,355	10,246	10,443	11,369
Total EU Species Feed Demand	11,232	13,769	11,872	11,779	13,940	12,813	13,691	12,564	14,648	14,257	15,287
Global Species Feed Demand	99,032	90,572	82,675	71,179	68,540	84,815	93,252	90,566	93,848	86,260	88,108

Figure 83 – Estimated EU feed material demand for turbot (tonnes) (2023)



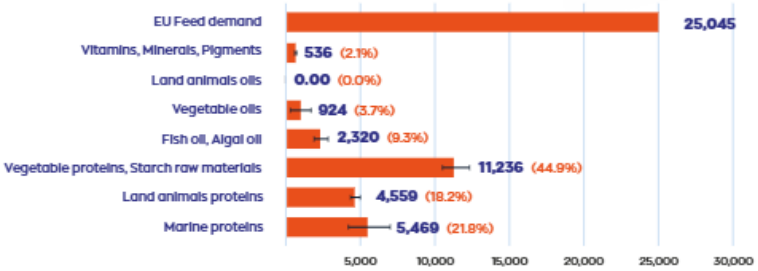
9.12. EU Material Demand



EU 2023 Aquafeed and materials demand per species (in metric tonnes) (2/3)

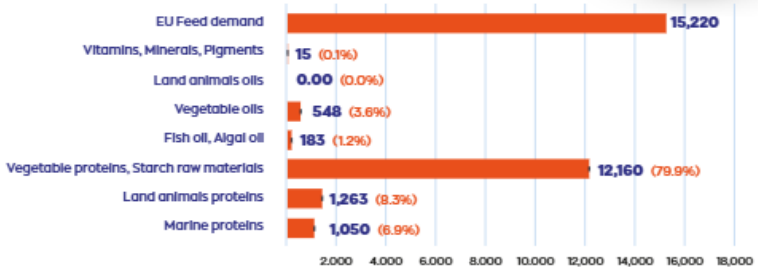
Meagre
(Argyrosomus regius)





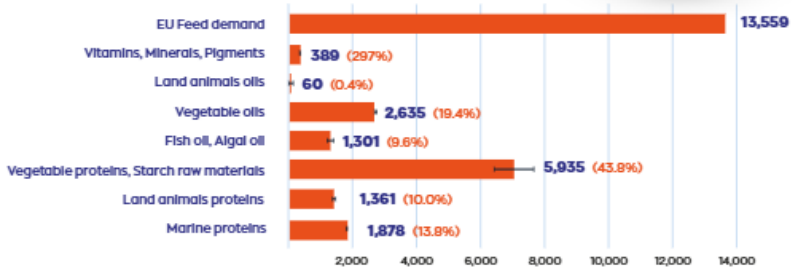
Turbot
(Scophthalmus maximus)





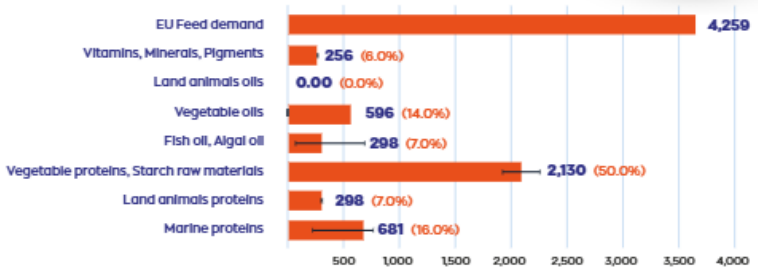
Atlantic salmon
(Salmo salar)





Sturgeon
(Acipenser spp. and Huso spp)



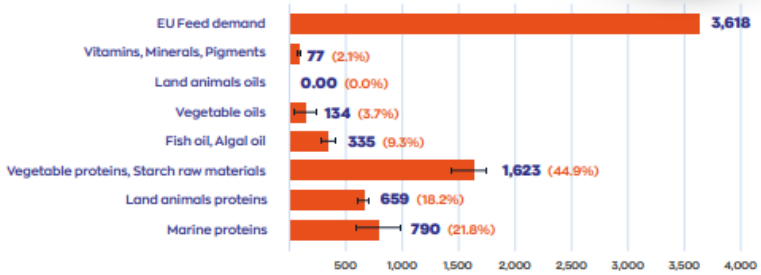


EU 2023 Aquafeed and materials demand per species (in metric tonnes) (3/3)

Sole

Solea solea/Solea senegalensis)

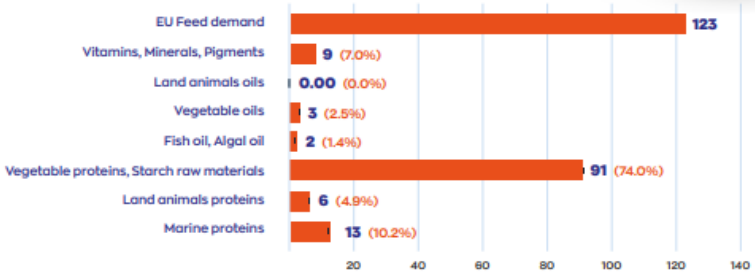




Shrimp

(Litopenaeus vannamei)

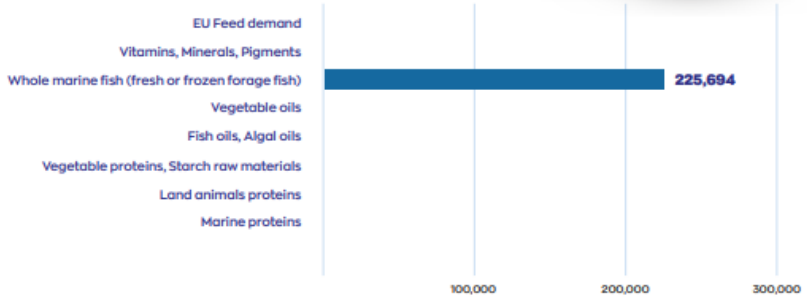




Bluefin tuna

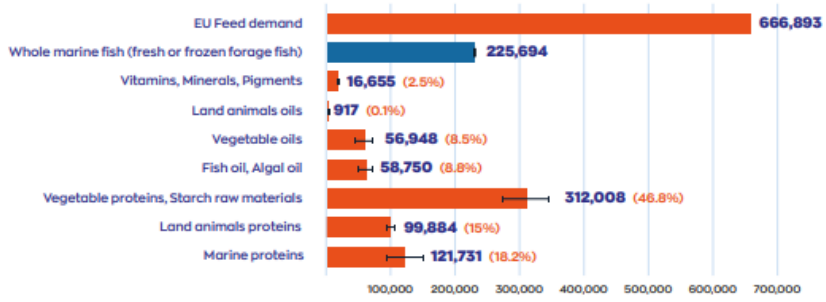
*(Thunnus thynnus)**

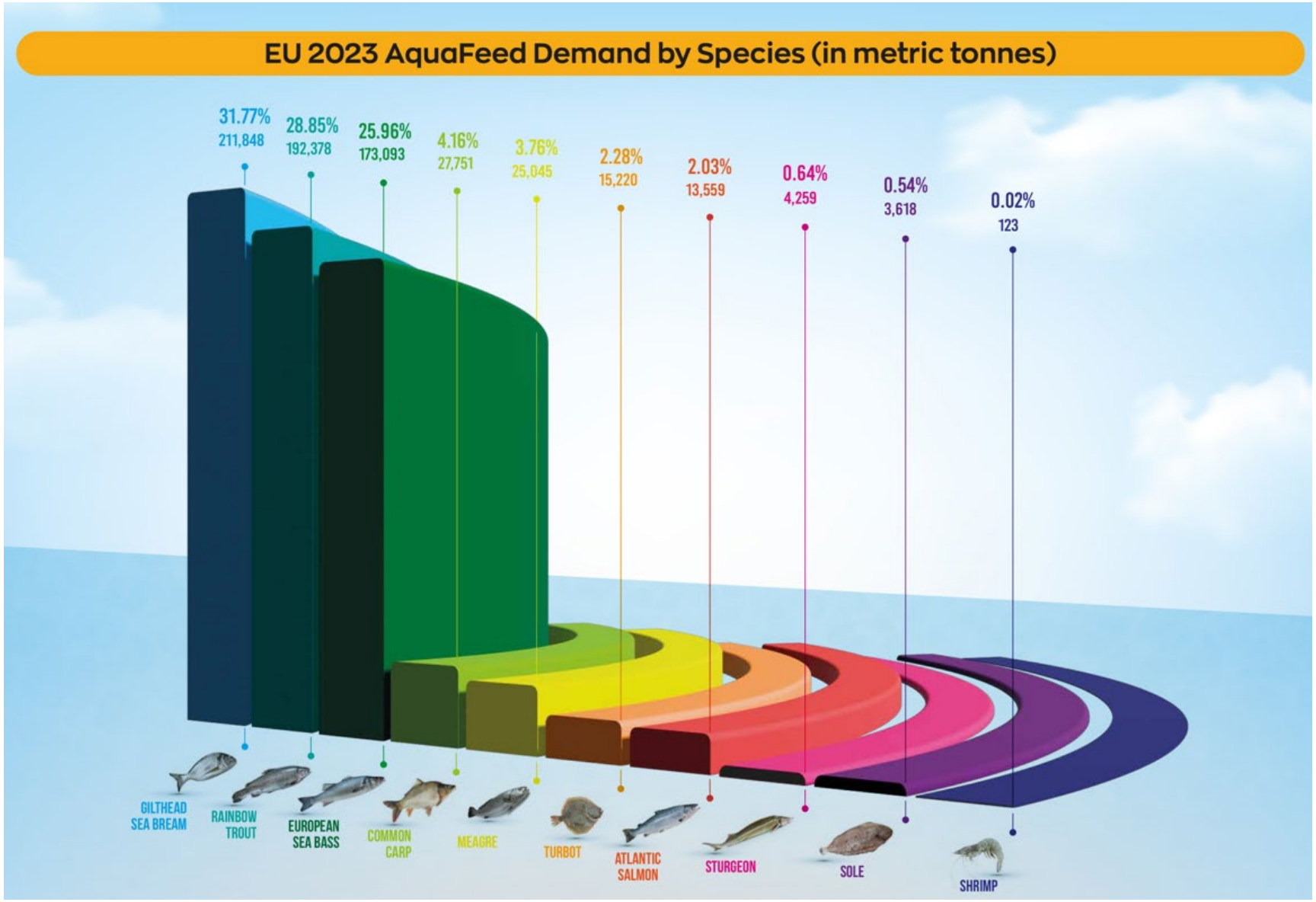




**Farmed bluefin tuna are fed whole marine fish (fresh or frozen forage fish such as sardines and mackerel) and do not consume pelleted aquafeeds.*

Total Aquafeed demand EU 2023




EU 2023 AquaFeed Demand by Species (in metric tonnes)
31.77%
211,848
28.85%
192,378
25.96%
173,093
4.16%
27,751
3.76%
25,045
2.28%
15,220
2.03%
13,559
0.64%
4,259
0.54%
3,618
0.02%
123
GILTHEAD SEA BREAM
RAINBOW TROUT
EUROPEAN SEA BASS
COMMON CARP
MEAGRE
TURBOT
ATLANTIC SALMON
STURGEON
SOLE
SHRIMP

10. Annex 4 Additional information on aquafeed materials

10.1. Fishmeal and fish oil

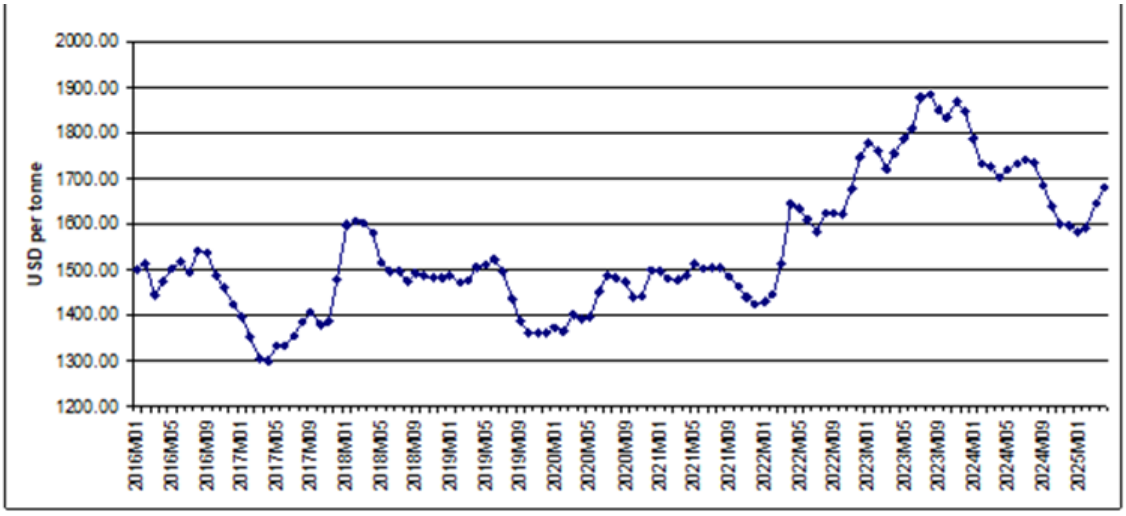
The aquaculture sector is the primary consumer of fishmeal and fish oil, accounting for about 92% of global consumption in 2023 (EUMOFA, 2025). According to EFFOP (2024) data, approximately 87.8% of fishmeal produced is used by the aquaculture sector – primarily for feeding crustaceans (23%), salmon and trout (16%), and other marine fish (20%). A small amount of fishmeal and fish oil are also used in livestock feed; the pig industry fishmeal use has gone from a 25% share in 2009 to only 3% in 2023 and was the third largest consumer of fishmeal. Fishmeal in poultry feed accounted for 1% of total consumption in 2023. In total, 5% of the global consumption was used as a feed material in other sectors (EUMOFA, 2025). Scientific evidence suggests that continued growth in aquaculture does not necessarily imply an increase in fishmeal and fish oil demand (FAO, 2025a). Innovations in feed formulation allow for reduced reliance on fishmeal, with an increasing share of production derived from by-products. The FAO projects that fishmeal from by-products will rise from 30% of total production today to 34% by 2030 (FAO, 2024a). Nevertheless, the dietary inclusion of fishmeal in aquaculture formulations is expected to decline from 5% in 2019–2021 to 4% by 2031, while the use of oilseed meals is projected to grow, reaching 10% of total fish feed use by 2031 (FAO/OECD, 2022).

Production of fishmeal and fish oil is anticipated to grow modestly over the outlook period, reaching 5.6 Mt and 1.3 Mt, respectively, by 2031. This represents an annual growth rate of 1.3% for fishmeal, slightly faster than the 1.1% per year recorded in the previous decade (OECD/FAO, 2024). Despite this growth, total production will remain below pre-2005 levels. Advances in processing technology, particularly the use of by-products from fisheries and aquaculture, are expected to play a significant role in meeting future demand (FAO, 2025a).

Fishmeal and fish oil are increasingly viewed as strategic materials used at specific stages of fish production, rather than as bulk feed components (OECD/FAO, 2024). Feed formulators are under pressure to develop cost-effective diets that meet nutritional requirements while minimizing environmental and social impacts. Improving traceability and responsible sourcing of all aquafeed materials, including fishmeal, is essential to ensure the long-term sustainability of the sector and protect global food and nutritional security (FAO, 2025a).

According to the World Bank (2025), fishmeal prices on the global market have exhibited notable fluctuations over the past decade (2016–2025). According to World Bank data (2025), average annual fishmeal prices ranged from approximately USD 1,366.97/t in 2017 to a peak of USD 1,814.89/t in 2023. After a relatively stable period from 2016 to 2020, when average prices remained in the range of USD 1,430–1,520/t, the market experienced a sharp increase in 2022–2023, driven by supply constraints, raw material shortages, and strong demand from the aquafeed sector. In 2024 and 2025, prices moderated slightly but remained elevated compared to pre-2022 levels, averaging USD 1,699.08/t in 2024 and USD 1,624.76/t in 2025. These trends highlight the sensitivity of fishmeal prices to fluctuations in raw material availability (such as small pelagic fish stocks), competition from alternative protein sources, and global market dynamics, including rising demand from aquaculture producers in Asia and Europe.

Figure 84 – Global fishmeal prices (USD/t) between 2016 and 2025



Source: World Bank (2025)

Fish oil prices have historically been more volatile than those of plant-based oils, mainly due to fluctuations in supply driven by fisheries quotas. In 2022, the average global price of fish oil reached approximately USD 3,900/t, primarily as a result of limited raw material availability. In 2023, prices continued to rise after Peru cancelled its first anchovy fishing season, a major source of fish oil. The second season also saw significantly reduced oil yields, producing only about 6,000 tonnes of fish oil, further driving prices up (Mowi, 2024).

There is a trend toward substitution of fishmeal and fish oil with alternatives such as soy protein, plant oils, animal by-products, microalgae, insect protein, and single-cell protein (Carter & Codabaccus, 2022; Eroldoğan *et al* 2023; Maulu *et al* 2022; Herath, 2022; Hardy, 2010). The evolving composition of salmon feed over the past decades illustrates the industry's efforts to reduce reliance on marine-derived materials. In 1990, the average Norwegian salmon diet comprised 65% fishmeal and 24% fish oil. By 2023, Mowi, the world's largest salmon producer, had reduced these proportions to 17% fishmeal and

13% fish oil in its salmon feed formulations (Mowi, 2024). This transition reflects both sustainability considerations and economic factors, as the industry seeks to balance nutritional requirements with environmental impact and resource availability. Innovative processing techniques (fermentation, enzymatic hydrolysis) and finishing diets with high-DHA oils help maintain fish health and fillet quality (Hossain *et al,* 2022; Xu *et al,* 2021). Despite these trends, fishmeal and fish oil remain critical, particularly for early life stages, carnivorous species, and health-promoting compounds. Balancing nutrition, cost, and sustainability is key for future aquafeed development (OECD/FAO, 2024; FAO, 2025a; EUMOFA, 2025).

10.2. Soy

10.2.1. Soybean meal

Soybean meal has been successfully used to replace fish meal in the diets of a variety of aquaculture species. Partial replacement—typically up to 50%—has been shown to maintain or even improve growth rates, feed efficiency, and body composition, particularly when amino acid supplementation is used to balance the nutrient profile. Some studies have even reported higher replacement levels with acceptable outcomes, depending on species and diet formulation (Arriaga-Hernández *et al,* 2021; Nasr *et al* 2021; Reda *et al,* 2021; Zakaria *et al,* 2022; Howlader *et al* 2023). Similarly, soybean oil has been examined as a substitute for fish oil, with moderate inclusion levels (6–9% of the diet) supporting optimal growth and health in species such as grass carp and *Totoaba macdonaldi*. However, higher inclusion rates (above 9–12%) have been associated with reduced growth, altered liver health, and imbalanced fatty acid profiles in fillets, underscoring the need for careful formulation (Maldonado-Othón *et al* 2020; Chen *et al* 2024a).

The economic benefits of replacing fish meal and fish oil with soybean-derived materials are significant. Feed costs are a major component of aquaculture production expenses, and soybean products offer a less expensive protein and energy source compared to marine materials. Studies have shown that using soybean meal, especially when combined with synthetic amino acids to improve the amino acid profile, can substantially lower feed costs while maintaining fish growth and health outcomes (Nasr *et al* 2021; Reda *et al* 2021). However, the nutritional quality of soybean products can vary based on processing methods and raw material origin, with factors such as protein dispersibility index, urease activity, and antinutritional compounds (e.g., glycinin, saponins) influencing digestibility, gut health, and immune responses (Zhou *et al* 2018).

In terms of fish health and immunity, moderate inclusion of soybean meal—up to 50% of the diet—has generally been found to maintain immune function,

antioxidant status, and disease resistance across species. Nevertheless, complete replacement of fish meal with soybean meal has been associated with reduced immune parameters and higher mortality risks in some studies, indicating the need for careful balancing of diet formulations (Zhou *et al* 2018; Reda *et al* 2021; Zakaria *et al* 2022). Additionally, antinutritional factors in soybean products can impair gut integrity, alter microbiota composition, and affect overall fish welfare, especially at high inclusion levels. Processing technologies such as fermentation and the use of high-oleic soybean varieties can mitigate some of these limitations, enhancing nutrient availability and reducing the negative impacts of antinutritional compounds (Patino *et al* 2024; Zakaria *et al* 2022).

One of the key challenges associated with the use of soybean oil in aquafeeds relates to its impact on the fatty acid composition of fish fillets. While soybean oil is a readily available and affordable lipid source, it is predominantly composed of n-6 polyunsaturated fatty acids, and its inclusion in aquafeeds often leads to a reduction in the beneficial n-3 fatty acids that are essential for human health. This shift in fatty acid profiles can lower the nutritional value of aquaculture products for consumers, highlighting a trade-off between feed cost savings and fillet quality (Maldonado-Othón *et al* 2020; Chen *et al* 2024a). Some studies suggest that alternative lipid sources, such as microalgal oils, may help maintain n-3 content while providing a sustainable alternative to fish oil.

Soybean cultivation and processing hold significant global importance. Brazil, the United States, and Argentina lead worldwide soybean production, accounting for 80% of the global output in 2024/2025 (Table 83; USDA, 2025a). Within the European Union, Italy (1.08 Mt), France (0.40 Mt), and Romania (0.29 Mt) are the top producers (Table 84; EC, 2025), although EU production (2.9 Mt) remains far below domestic demand. As a result, the EU remains heavily dependent on soybean imports, mainly from the Americas.

The European soy trade is highly concentrated in just a few member states, creating both logistical efficiencies and systemic vulnerabilities. Approximately 80% of the EU’s soybean imports are channelled through the Netherlands, Spain, Germany, and Italy, reflecting the dominance of a limited number of entry points and processing hubs. Similarly, soybean meal imports are concentrated in Spain, the Netherlands, Poland, France, and Italy, which together account for around 63% of the total volume (Fediol, 2020). This geographic concentration underscores the EU aquaculture sector’s dependence on a narrow set of supply chains, making it more exposed to trade disruptions, price volatility, and environmental risks linked to soybean production. In this context, ensuring supply chain resilience—through diversification of sources, greater traceability, and wider adoption of sustainability certification schemes—becomes critical to securing the long-term sustainability and competitiveness of European aquaculture systems.

Another key regulatory challenge relates to the use of genetically modified (GM) soybeans in aquafeed. Although GM soy is legally authorised for feed use under EU Regulation (EC) No 1829/2003, each genetically modified line must undergo a case-by-case risk assessment by the European Food Safety Authority (EFSA) before approval. This process is often lengthy, costly, and subject to political uncertainty, creating barriers for importers and feed manufacturers. Moreover, consumer perceptions in Europe remain largely unfavourable towards GM products, exerting additional pressure on aquaculture companies to avoid their use. As a result, despite the cost-efficiency and high availability of GM soy in global markets, most EU aquafeed producers continue to prioritise certified non-GMO soy alternatives (FAO, 2025b). This reliance on non-GMO soy not only increases feed costs but also intensifies the need for reliable certification schemes and diversified sourcing strategies to secure long-term supply for the aquaculture sector.

In terms of sustainability, soy protein concentrate has a carbon footprint of approximately 1,500 kg CO_2eq/t due to the extra processing that is required for its production, while standard SBM has a lower footprint of 500 kg CO_2eq/t, making it one of the more sustainable plant-based protein options in aquafeed compared to animal proteins or highly refined isolates (Table 86; IAFFD, 2025).

Table 83 – Top 10 worldwide soybean producers by volume (Mt) (2024/25)

Market	% of Global Production	Total Production (million tonnes)
Brazil	40	169.0
United States	28	118.8
Argentina	12	49.0
China	5	20.7
India	3	12.6
Paraguay	3	10.7
Canada	2	7.6
Russia	2	7.1
Ukraine	2	7.0
Bolivia	1	4.1

Source: USDA (2025a).

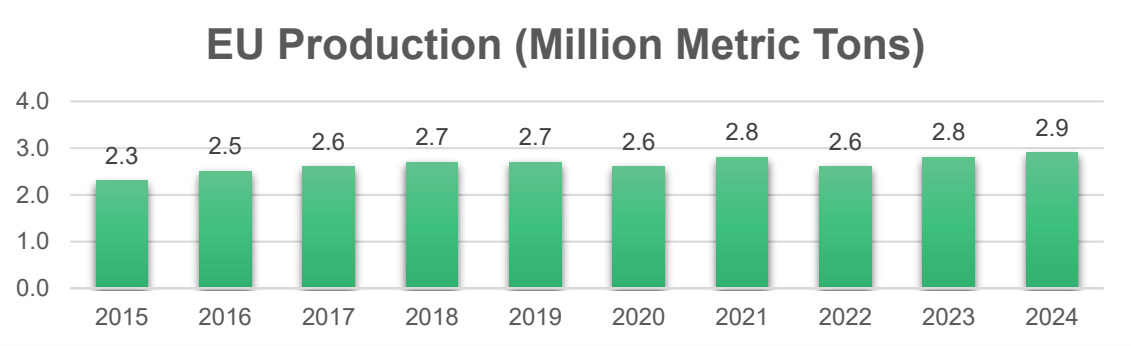
Table 84 – Top 10 EU soybean producers by volume (Mt) (2024/25)

EU Producer	EU Production (million tonnes)
Italy	1.08
France	0.40
Romania	0.29
Croatia	0.25

EU Producer	EU Production (million tonnes)
Hungary	0.25
Austria	0.25
Slovakia	0.15
Germany	0.13
Poland	0.08
Czechia	0.07

Source: EC, 2025

Figure 85 – Soybean gross production by volume (Mt) for EU Member States and UK (2015-2024)



Source: EC (2025b).

Table 85 – Top 10 largest importers and exporters of soybeans in the European Union and UK by value (‘000 EUR) in 2024

Importers	Imported	Exporters	Exported
World	79,946,310	World	73,624,922
EU 27 & UK aggregation	7,394,293	EU 27 & UK aggregation	934,017
Germany	1,680,765	Netherlands	215,697
Spain	1,534,379	Croatia	109,988
Italy	1,131,422	Romania	108,596
Netherlands	1,109,169	Austria	91,037
Portugal	483,119	Hungary	70,510
United Kingdom	473,262	Belgium	68,200
France	279,232	Poland	67,954
Belgium	181,166	France	55,262
Norway	179,942	Slovakia	52,748
Greece	104,257	Germany	24,732

Source: ITC (2025).

Table 86 – Nutritional profile of the most common soybean products used as raw materials in aqua feeds

Raw Materials	Soy protein concentrate 65% CP	Soy protein isolate	Soybean meal, dehulled, 48% CP, solvent extracted	Fermented soybean meal 53% CP
Dry Matter (%)	92.5	93	89.81	92
Moisture (%)	7.5	7	10.19	8
Crude Protein (%)	65.3	83.6	48.9	53.2
Crude Lipids (%)	0.77	0.5	1.39	0.8
Crude Fibre (%)	3.78	0.1	4.04	3.5
Ash (%)	6.26	3.5	6.24	6.8
Gross Energy (MJ/kg)	19.1	20.8	17.7	18.2
Lysine (%)	4.23	4.31	2.75	3.44
Methionine (%)	0.92	1.08	0.66	0.92
Threonine (%)	2.73	3.03	1.94	1.96
Phosphorus (%)	0.799	0.68	0.65	0.8
Carbon Footprint (kg CO_2eq/t)	1,500	2,000	500	1,000

Source: IAFFD (2025).

Table 87 – Evolution of market price (EUR/t) for soybean products

Soybean products	2020	2021	2022	2023	2024
Soybean meal ([163])	365	410	520	500	430
SPC ([164])	850	950	1,200	1,050	980
FSBM ([165])	700	800	950	880	820

SPC and Fermented Soybean Meal (FSBM) prices were generally higher than soybean meal prices, especially in 2021 and 2022. Both commodities peaked in 2022, reflecting global market disruptions. Prices for both declined in 2023 and 2024, with soybean meal showing a slightly more stable trend.

SPC commanded a premium over soybean meal, typically ranging from EUR 850-1,200/t, depending on protein content, origin, and application (e.g.

([163]) https://www.indexmundi.com/commodities/?commodity=soybeans&months=360&currency=eur

([164]) https://www.mordorintelligence.com/industry-reports/europe-soy-protein-market & https://www.futuremarketinsights.com/reports/soy-protein-concentrate-market

([165]) https://www.globalinforesearch.com/reports/2365117/fermented-soybean-meal--fsbm

feed versus food-grade). In 2022, during peak commodity prices, SPC prices in Europe reportedly reached EUR 1,100-1,300/t. By 2024, prices had moderated to around EUR 950-1,050/t, reflecting easing supply chain pressures and stabilised demand.

FSBM is a value-added product used primarily in young animal feed (especially piglets and aquaculture), and it typically trades at a premium over standard soybean meal due to improved digestibility and reduced anti-nutritional factors. The price premium over regular soybean meal is usually in the range of EUR 200-400/t, depending on origin, fermentation process, and protein content.

10.2.2. Soybean oil

Globally, China (19.6 Mt), the United States (13.1 Mt), and Brazil (11.6 Mt) are the top producers of soybean oil, accounting for over 65% of world production in 2024/2025 (Table 88; USDA, 2025b). Within the European Union, the Czech Republic (0.93 Mt), Germany (0.62 Mt) and the Netherlands (0.58 Mt) lead in production (Source: USDA (2025b).

Table 89; EC, 2025). EU production trends from 2015 to 2025 reflect steady growth in soybean oil processing and consumption, as illustrated in Figure 86 (EC, 2025).

In terms of trade, the EU imported EUR 1.44 billion and exported EUR 1.35 billion worth of soybean oil in 2024, with Spain, Poland and the United Kingdom being major importers, and the Netherlands, Spain and Italy among the top exporters (Table 90; ITC, 2025).

Table 88 – Top 10 worldwide soybean oil producers by volume (Mt) (2024/25)

Market	% of Global Production	Total Production (million tonnes)
China	29	19.6
United States	19	13.1
Brazil	17	11.6
Argentina	12	8.4
European Union	4	2.9
India	3	2.0
Mexico	2	1.2
Russia	2	1.1
Egypt	1	0.6
Paraguay	1	0.6

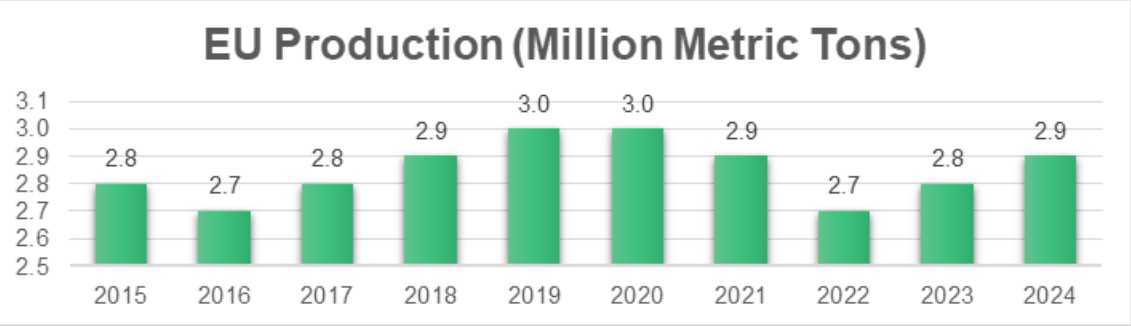
Source: USDA (2025b).

Table 89 – Top 10 EU soybean oil producers by gross production (Mt) (2024/25)

EU Producer	EU Production (million tonnes)
Czech Republic	0.93
Germany	0.62
Netherlands	0.58
Spain	0.56
Italy	0.41
Sweden	0.30
Portugal	0.21
Denmark	0.08
France	0.08
Romania	0.06

Source: FAO (2025b).

Figure 86 – Soybean oil gross production by volume (Mt) for EU Member States and UK (2015-2024)



Source: FAO (2025b).

Table 90 – Top 10 largest importers and exporters of soybean oil in the European Union and UK by value (‘000 EUR) in 2024

Importers	Imported	Exporters	Exported
World	12,246,111	World	11,361,652
EU 27 & UK Aggregation	1,436,788	EU 27 & UK Aggregation	1,351,427
Spain	267,387	Netherlands	411,155
Poland	244,155	Spain	282,876
United Kingdom	178,956	Italy	146,311
Germany	164,626	Portugal	118,859
Netherlands	129,573	Poland	94,351
Belgium	90,844	France	84,822
Ireland	66,915	Germany	75,711

Importers	Imported	Exporters	Exported
Italy	66,501	Norway	61,407
Denmark	33,476	United Kingdom	35,532
Bulgaria	30,455	Belgium	26,276

Source: ITC (2025).

Table 91 – Nutritional profile of soybean oil used as raw material in aqua feeds

Description	Soybean oil
Palmitic 16:0 (%)	9.4
Stearic 18:0 (%)	4.0
Oleic 18:1 n-9 (%)	21.8
Linoleic 18:2 n-6 (%)	51.0
Linolenic 18:3 n-3 (%)	6.8
Arachidonic 20:4 n-6 (%)	0.0
EPA 20:5 n-3 (%)	0.0
DHA 22:6 n-3 (%)	0.0
EPA+DHA (%)	0.0
SAFA (%)	15.1
MUFA (%)	23.2
PUFA (%)	57.8
Sum n-3 (%)	7.6
Sum n-6 (%)	56.7
Phospholipids (%)	1.1
Carbon Footprint (kg CO_2eq/t)	1,000.0

Source: IAFFD (2025).

Table 92 – Evolution of market price (EUR/t) for soybean oil

Material	2020	2021	2022	2023	2024
Soybean oil ([166])	765	1,180	1,670	1,020	950*

*2024 prices are estimates.

Prices peaked in 2022, driven by global supply chain disruptions and increased demand for vegetable oils. A sharp decline followed in 2023 and 2024,

([166]) https://www.indexmundi.com/commodities/?commodity=soybean-oil&months=60&currency=eur

reflecting improved supply and lower energy costs. These prices are based on crude soybean oil, f.o.b. ex-mill Netherlands, a common benchmark in Europe.

10.3. Maize gluten meal (corn)

Globally, the United States is the largest global producer of maize in 2024/25 marketing year (377.6 Mt), accounting for 31% of production. Other major producers include China (294.9 Mt) and Brazil (132.0 Mt) (Table 93). The EU, producing 59.3 Mt, is led by France (14.7 Mt), Poland (9.2 Mt), and Romania (6.5 Mt) (Table 94).

Trends in production across the EU between 2015 and 2024 are illustrated in Figure 87, highlighting national contributions and regional shifts in maize output (EUROSTAT, 2025) . The EU is both a major importer and exporter of maize products. Table 95 details maize trade in terms of value. In 2024, Spain, Italy, and the Netherlands were the top importers, while France, Romania, and Hungary led exports. This trading ecosystem ensures the availability of CGM throughout the EU, supporting regional aquaculture production.

Table 93 – Top 10 worldwide maize producers by volume (Mt) (2024/25)

Market	% of Global Production	Total Production (million tonnes)
United States	31	377.6
China	24	294.9
Brazil	11	132.0
European Union	5	59.3
Argentina	4	50.0
India	3	42.3
Ukraine	2	26.8
Mexico	2	23.1
South Africa	1	15.8
Canada	1	15.4

Source: USDA (2025b).

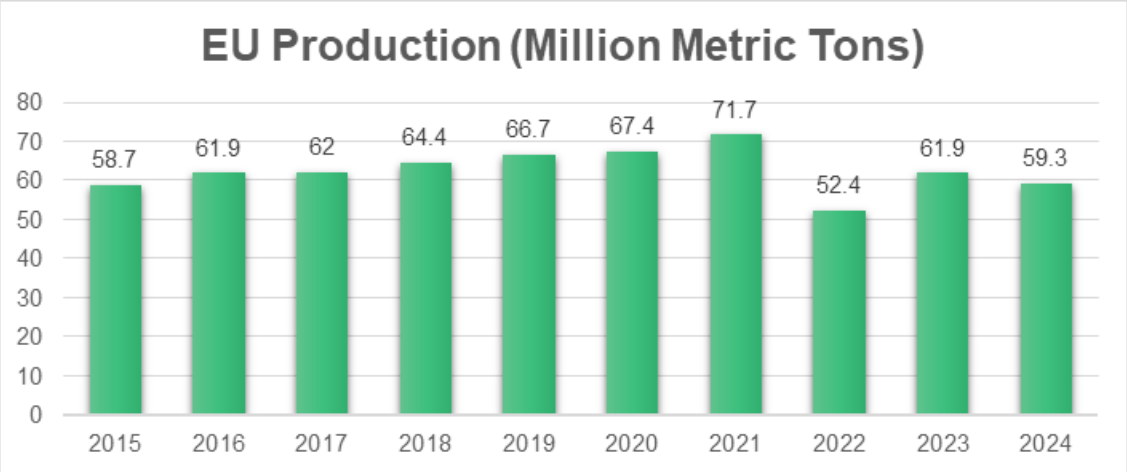
Table 94 – Top 10 EU maize producers by volume (Mt) (2024/25)

EU Maize Producer	EU Production (million tonnes)
France	14.7
Poland	9.2
Romania	6.5
Hungary	5.2
Germany	5.0

EU Maize Producer	EU Production (million tonnes)
Italy	4.9
Spain	3.3
Croatia	2.1
Austria	2.1
Bulgaria	1.6

Source: USDA, 2025b; EC, 2025

Figure 87 – Maize gross production by volume (Mt) for EU Member States and UK (2015-2024)



Source: EC (2025).

Table 95 – Top 10 largest importers and exporters of maize in the European Union and UK by value (‘000 EUR) in 2024

Importers	Imported	Exporters	Exported
World	47,783,454	World	41,878,468
EU 27 & UK Aggregation	9,658,179	EU 27 & UK Aggregation	5,648,907
Spain	1,981,220	France	1,721,596
Italy	1,657,734	Romania	822,647
Netherlands	1,178,923	Hungary	799,716
Germany	881,900	Poland	714,328
United Kingdom	712,984	Austria	318,748
Portugal	413,411	Croatia	233,164
Belgium	409,741	Bulgaria	183,654
Austria	357,730	Germany	168,595
Ireland	331,399	Spain	113,136
France	311,041	Netherlands	92,491

Source: ITC, 2025

Energy density and amino acid balance are key determinants for aquafeed efficiency (Konnert et al., 2022). While CGM cannot fully replace fishmeal or soy

protein concentrates, it can serve as a valuable supplemental material in balanced formulations. The carbon footprint of CGM (900 kg CO_2eq/t) also compares favourably with other protein sources, offering sustainability advantages (Table 96).

Table 96 – Nutritional profile of maize gluten meal (60% CP) products used as raw materials in aqua feeds

Nutrient	% Composition
Dry Matter (%)	90.9
Moisture (%)	9.1
Crude Protein (%)	59.9
Crude Lipids (%)	1.6
Crude Fibre (%)	2.0
Ash (%)	2.4
Gross Energy -MJ (MJ/kg)	19.4
Lysine (%)	1.1
Methionine (%)	1.4
Threonine (%)	2.0
Phosphorus (%)	0.4
Carbon Footprint (kg CO_2eq/t)	900.0

Source: IAFFD (2025).

Table 97 – Evolution of market price (EUR/t) for maize gluten meal

Material	2020	2021	2022	2023	2024
Maize gluten meal ([167])	580	640	750	700	660

Prices peaked in 2022, in line with broader feed material inflation. CGM typically trades at a premium over maize grain due to its high protein content (~60%). These values are based on EU import and feed market data, particularly from Rotterdam and Hamburg ports, which are key reference points.

10.4. Rapeseed & canola

10.4.1. Rapseed-canola meal

Globally, Canada (22%), the EU (20%), and China (18%) are the leading global producers of rapeseed-canola meal, with Canada producing over 19 Mt in

([167]) https://agridata.ec.europa.eu/extensions/DataPortal/cereals.html & https://teseo.clal.it/en/?section=cereals_price_eu

2024/2025 (USDA, 2025b) (Table 98). EU production is concentrated in France (3.9 Mt), Germany (3.6 Mt), and Poland (3.3 Mt), as shown in Table 99. Production trends across EU Member States are visualized in Figure 88, which shows a relatively stable upward trend in gross output between 2015 and 2025 (EC, 2025).

As for the trade dynamics, the EU is a major importer and exporter of rapeseed-canola meal (call it double-zero rapeseed (00 rapeseed). In 2024, Germany and Belgium led imports by value, while France and Romania dominated exports (Table 100). This active trade network enables feed manufacturers to access consistent supplies of RSM throughout the EU.

Table 98 – Top 10 worldwide rapeseed-canola meal producers by volume (Mt) (2024/25)

Market	% of Global Production	Total Production (million tonnes)
Canada	22	19.2
European Union	20	16.9
China	18	15.8
India	13	11.5
Australia	7	6.1
Russia	5	4.7
Ukraine	4	3.8
United States	3	2.2
Bangladesh	2	1.4
Belarus	1	1.1

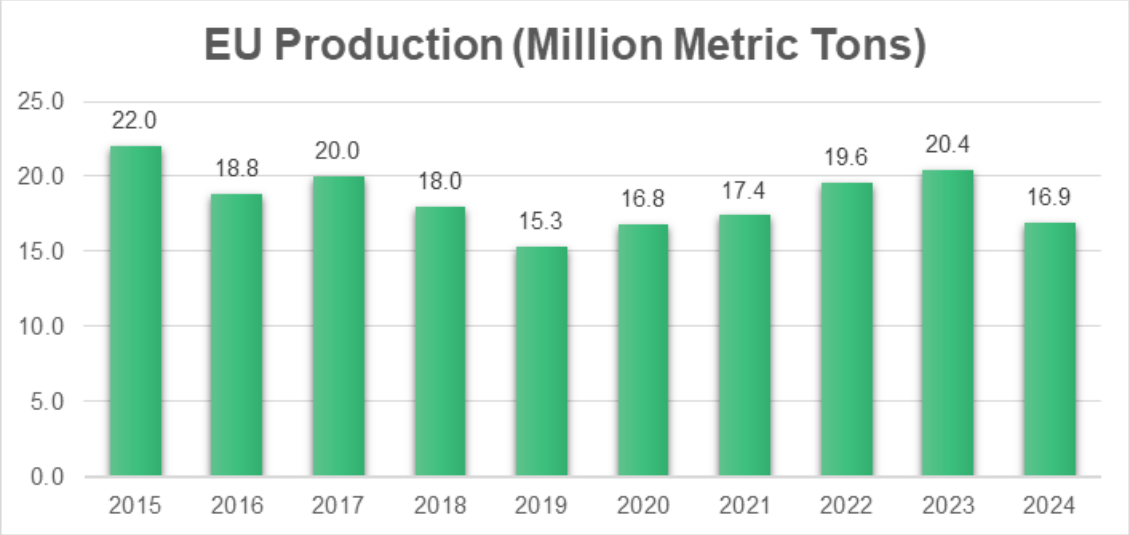
Source: (USDA, 2025b)

Table 99 – Top 10 EU rapeseed-canola meal producers by volume (Mt) (2024/25)

EU Producer	EU Production (million tonnes)
France	3.9
Germany	3.6
Poland	3.3
Romania	1.2
Czechia	0.9
Lithuania	0.9
Denmark	0.7
Hungary	0.4
Slovakia	0.4
Sweden	0.3

Source: EC, 2025

Figure 88 – Rapeseed-canola meal gross production by volume (Mt) for EU Member States and UK (2015-2024)



Source: (EC, 2025;)

Table 100 – Top 10 largest importers and exporters of rapeseed-canola meal in the EU and UK by value (‘000 EUR) in 2024

Importers	Imported	Exporters	Exported
World	12,869,321	World	12,605,705
EU 27 & UK Aggregation	6,880,682	EU 27 & UK Aggregation	3,516,444
Germany	2,806,109	France	710,544
Belgium	1,293,260	Romania	536,835
France	568,874	Belgium	461,675
Netherlands	525,983	Hungary	293,771
United Kingdom	373,783	Lithuania	287,529
Poland	200,683	Netherlands	211,382
Czech Republic	191,980	Poland	189,890
Austria	140,223	Czech Republic	178,316
Greece	102,121	Latvia	139,729
Romania	93,648	Germany	136,768

Source: (ITC, 2025)

Table 101 – Nutritional profile of rapeseed-canola meal products used as raw materials in aqua feeds

Nutrient	% Composition
Dry Matter (%)	91.6
Moisture (%)	8.4
Crude Protein (%)	39.1
Crude Lipids (%)	3.5
Crude Fibre (%)	11.4

Nutrient	% Composition
Ash (%)	6.4
Gross Energy -MJ (MJ/kg)	17.8
Lysine (%)	1.9
Methionine (%)	0.7
Threonine (%)	1.6
Phosphorus (%)	1.2
Carbon Footprint (kg CO_2eq/t)	400.0

Based on rapeseed/canola meal, solvent extracted, 39% CP
Source: IAFFD (2025).

Antinutritional compounds, such as glucosinolates, can negatively impact thyroid metabolism and feed intake in fish. However, solvent extraction**,** heat treatment and fermentation have been shown to significantly reduce ANF concentrations and improve palatability and digestibility (Kumar *et al*., 2025, Glencross *et al*., 2020). Enzyme supplementation, especially with phytase, can also enhance phosphorus bioavailability from RSM, addressing one of the key nutritional limitations in non-ruminant animals including fish (Kumar *et al*., 2011).

Table 102 – Evolution of market price (EUR/t) for rapeseed-canola meal

Material	2020	2021	2022	2023	2024
Rapeseed (Canola) meal ([168])	260	310	360	330	295

Prices peaked in 2022, in line with other protein meals due to global supply chain disruptions. In 2024, prices averaged around EUR 295/t, with some regional variations (e.g., Northern Germany saw prices near EUR 330/t in early 2025). Rapeseed meal is a widely used protein source in European livestock feed, especially in dairy and ruminant diets.

10.4.2. Rapeseed-canola oil

Globally, the EU is the leading producer, generating 9.85 Mt of rapeseed oil in 2024/2025, followed by China (7.84 Mt) and Canada (4.88 Mt) (Table 103; USDA, 2025b). Within the EU, Germany (3.72 Mt), France (1.84 Mt), and Poland (1.36 Mt) are the top producers (Table 104; EC, 2025). Production trends across EU Member States from 2015 to 2025 indicate steady rapeseed oil output growth, as visualized in Figure 89 (EC, 2025).

In terms of trade, the EU imported EUR 3.66 billion and exported EUR 4.23 billion of rapeseed oil in 2024, indicating strong regional demand and

([168]) https://ukragroconsult.com/en/news/rapeseed-meal-shortage-worsens-on-global-markets/

competitiveness (Table 104; ITC, 2025). Major importers include the Netherlands, Belgium and Norway, while key exporters include Germany, France, and the Netherlands (ITC, 2025).

Table 103 – Top 10 worldwide rapeseed oil producers by volume (Mt) (2024/25)

Market	% of Global Production	Total Production (million tonnes)
European Union	29	9.85
China	23	7.84
Canada	14	4.88
India	12	3.96
Russia	4	1.42
Japan	3	0.91
United States	2	0.82
United Kingdom	2	0.66
Bangladesh	2	0.63
Belarus	2	0.54

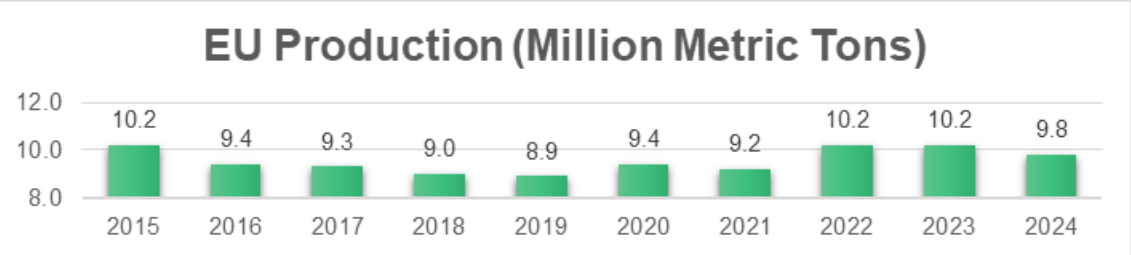
Source: (USDA, 2025b)

Table 104 – Top 10 EU rapeseed oil producers by volume (Mt) (2002)

EU Producer	EU Production (million tonnes)
Germany	3.72
France	1.84
Poland	1.36
Belgium	0.62
Czechia	0.40
Denmark	0.28
Netherlands	0.18
Romania	0.16
Sweden	0.15
Austria	0.14

Source: FAO (2025b).

Figure 89 – Rapeseed oil gross production by volume (Mt) for EU Member States and UK (2015-2024)



Source: FAO (2025b).

Table 105 – Top 10 largest importers and exporters of rapeseed-canola oil in the EU and UK by value (‘000 EUR) in 2024

Importers	Imported	Exporters	Exported
World	10,917,372	World	11,196,797
EU 27 & UK Aggregation	3,663,119	EU 27 & UK Aggregation	4,227,639
Netherlands	1,004,405	Germany	1,369,490
Belgium	504,706	France	612,163
Norway	460,137	Netherlands	502,248
Germany	407,465	Belgium	437,716
Sweden	218,090	Czech Republic	315,627
United Kingdom	206,299	Poland	201,730
Austria	194,580	Denmark	168,597
Poland	187,245	Estonia	83,084
France	174,994	Austria	82,936
Spain	143,655	United Kingdom	65,800

Source: (ITC, 2025)

Table 106 – Nutritional profile of rapeseed oil used as raw material in aqua feeds

Nutrient	% Composition
Palmitic 16:0 (%)	5.0
Stearic 18:0 (%)	2.2
Oleic 18:1 n-9 (%)	56.9
Linoleic 18:2 n-6 (%)	20.3
Linolenic 18:3 n-3 (%)	12.0
Arachidonic 20:4 n-6 (%)	0.0
EPA 20:5 n-3 (%)	0.0
DHA 22:6 n-3 (%)	0.0
EPA+DHA (%)	0.0
SAFA (%)	7.4
MUFA (%)	58.3

Nutrient	% Composition
PUFA (%)	32.2
Sum n-3 (%)	13.3
Sum n-6 (%)	22.6
Phospholipids (%)	1.7
Carbon Footprint (kg CO_2eq/t)	1,600.0

Source: IAFFD (2025).

Table 107 – Evolution of market price (EUR/t) for rapeseed-canola oil

Material	2020	2021	2022	2023	2024
Rapeseed oil ([169])	780	1,250	1,700	1,100	980
Canola oil (feed grade) ([170])([171])([172])	850	1,100	1,500	1,300	1,200

Prices peaked in 2022, driven by global shortages of vegetable oils, droughts in Canada and increased demand for biofuels. In 2023 and 2024, prices declined, reflecting improved supply and reduced energy costs, but remain above pre-pandemic levels.

10.5. Wheat gluten

Global wheat production is forecast to reach 796 Mt in 2025/26, representing a modest 1% increase over the previous year (FAO, 2025b). Production gains are expected in the European Union, especially in France and Germany, offsetting reductions elsewhere (FAO, 2025d). The EU consumes around 80% of its wheat crop, nearly two-thirds in animal feeds (European Commission, n.d).

Globally, China (140.1 Mt), the EU (122.1 Mt) and India (113.3 Mt) are the largest producers of wheat gluten meal (Table 108; USDA, 2025b). In the European Union, the leading producers are France (26.5 Mt), Germany (18.5 Mt) and Poland (12.2 Mt), accounting for over half of the total EU output (Table 109; EC, 2025). Figure 90 shows a steady increase in wheat gluten production across EU Member States from 2015 to 2025, supporting the growing demand for WGM in the feed and food industries (EC, 2025).

In terms of trade, the EU imported EUR 10.2 billion worth of wheat gluten meal in 2024, with Italy, Spain and Germany being top importers, while France, Romania and Germany led EU exports (Table 110; ITC, 2025).

([169]) https://tradingeconomics.com/commodity/rapeseed-oil
([170]) FAO – Food Outlook Reports - https://www.fao.org/giews/reports/food-outlook/en/
([171]) European Commission – Short-Term Outlook Reports - https://ec.europa.eu/newsroom/agri/items/893120/
([172]) OECD-FAO Agricultural Outlook - https://openknowledge.fao.org/handle/20.500.14283/cd1463EN

Table 108 – Top 10 worldwide wheat gluten producers by volume (Mt) (2024/25)

Trading Nation	% of Global Production	Total Production (million tonnes)
China	18	140.1
European Union	15	122.1
India	14	113.3
Russia	10	81.6
United States	7	53.7
Canada	4	35.0
Australia	4	34.1
Pakistan	4	31.4
Ukraine	3	23.4
Turkey	2	19.0

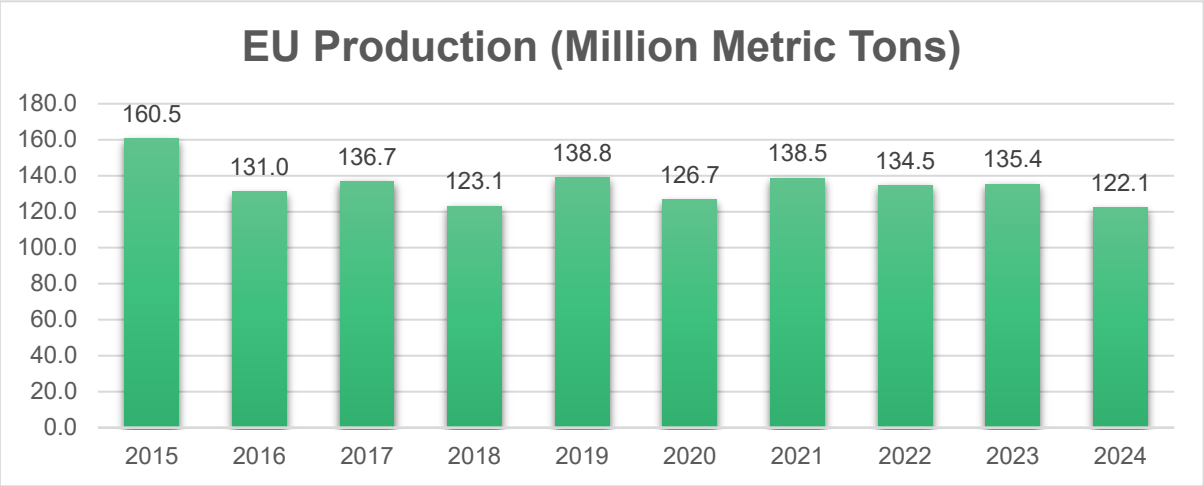
Source: USDA (2025b).

Table 109 – Top 10 EU wheat gluten meal producers by volume (Mt) (2024/2025)

EU Producer	EU Production (million tonnes)
France	26.5
Germany	18.5
Poland	12.2
United Kingdom	11.1
Romania	10.1
Spain	7.4
Bulgaria	7.1
Italy	6.2
Hungary	5.3
Czech Republic	4.6

Source: EUROSTAT, 2025

Figure 90 – Wheat gluten meal gross production by volume (Mt) for EU Member States and UK (2015-2024)



Source: EC, 2025b; EUROSTAT, 2025

Table 110 – Top 10 largest importers and exporters of wheat gluten meal in the EU and UK by value (‘000 EUR) in 2024

Importers	Imported	Exporters	Exported
World	52,562,015	World	47,649,411
EU 27 & UK Aggregation	10,166,133	EU 27 & UK Aggregation	13,448,545
Italy	2,560,486	France	3,432,824
Spain	1,718,882	Romania	1,645,508
Germany	1,343,491	Germany	1,568,154
Netherlands	980,363	Poland	1,132,110
Belgium	892,393	Bulgaria	1,072,354
United Kingdom	824,632	Hungary	889,860
Portugal	324,921	Lithuania	815,865
Greece	270,921	Czech Republic	651,237
Austria	242,796	Latvia	575,692
Romania	186,262	Slovakia	345,860

Source: ITC, 2025

Table 111 – Nutritional profile of wheat gluten meal used as raw material in aqua feeds

Nutrient	% Composition
Dry Matter (%)	90.7
Moisture (%)	9.3
Crude Protein (%)	78.2
Crude Lipids (%)	2.4
Crude Fibre (%)	0.4
Ash (%)	0.7

Nutrient	% Composition
Gross Energy -MJ (MJ/kg)	21.0
Lysine (%)	2.2
Methionine (%)	1.4
Threonine (%)	2.0
Phosphorus (%)	0.2
Carbon Footprint (kg CO_2eq/t)	3,300.0

Based on Wheat gluten meal, 78% CP

Source: IAFFD (2025).

Table 112 – Evolution of market price (EUR/t) for wheat gluten meal

Material	2020	2021	2022	2023	2024
Wheat gluten meal ([173])	1,100	1,324	1,646	2,055	1,431

Wheat gluten prices peaked in 2022 and 2023, driven by high energy costs, wheat price volatility, and strong demand from the food and feed sectors. Prices have since moderated but remain elevated compared to pre-2021 levels[174]. These values reflect feed-grade and food-grade wheat gluten, with some variation depending on origin (e.g., EU vs. China) and protein content.

10.6. Sunflower products

10.6.1. Sunflower meal

In global production terms, Russia (16.9 Mt), Ukraine (13.0 Mt) and the European Union (8.5 Mt) are the top producers, accounting for 73% of world output in 2024/2025 (Table 113; USDA, 2025b). Within the EU, Hungary (1.8 Mt), Bulgaria (1.6 Mt) and Romania (1.5 Mt) are the largest producers of SFM, as detailed in Table 114 (EC, 2025).

Production trends across the EU from 2015 to 2025 show steady growth in sunflower meal output, particularly in Eastern and Central Europe (Figure 91; EC, 2025). In terms of trade, the EU imported sunflower meal worth €2.57 billion in 2024, with Bulgaria, Netherlands and Romania among the top importers (Table 115; ITC, 2025). Meanwhile, Romania and France were leading exporters from the EU, with significant outbound value in processed sunflower meal (Table 115; ITC, 2025).

([173]) https://www.trademap.org/Country_SelProduct_TS.aspx?nvpm=1%7c%7c%7c%7c%7c1109%7c%7c%7c4%7c1%7c1%7c1%7c2%7c1%7c2%7c3%7c1%1

([174]) https://thedocs.worldbank.org/en/doc/40ebbf38f5a6b68bfc11e5273e1405d4-0090012022/related/Food-Security-Update-LXXX-March-09-2023.pdf

Table 113 – Top 10 worldwide sunflower meal producers by volume (Mt) (2024/25)

Trading Nation	% of Global Production	Total Production (million tonnes)
Russia	32%	16.9
Ukraine	25%	13.0
European Union	16%	8.5
Argentina	10%	5.1
Kazakhstan	3%	1.8
China	3%	1.8
Turkey	3%	1.4
Moldova	1%	0.7
South Africa	1%	0.7
Serbia	1%	0.6

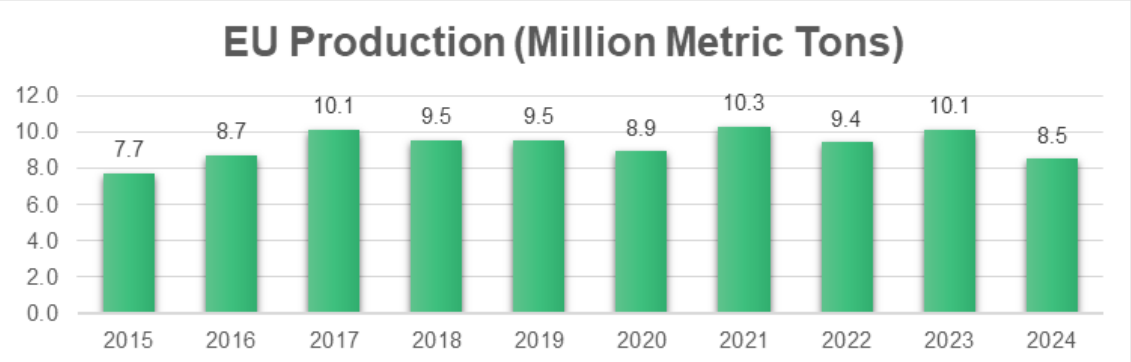
Source: USDA (2025b).

Table 114 – Top 10 EU sunflower meal producers by volume (Mt) (2024/25)

EU Producer	EU Production (million tonnes)
Hungary	1.8
Bulgaria	1.6
Romania	1.5
France	1.5
Spain	0.8
Italy	0.3
Croatia	0.2
Slovakia	0.2
Greece	0.2
Germany	0.1

Source: EC (2025a).

Figure 91 – Sunflower meal gross production by volume (Mt) for EU Member States and UK (2015-2024)



Source: EC (2025a).

Table 115 – Top 10 largest importers and exporters of sunflower meal in the EU and UK by value (‘000 EUR) in 2024

Importers	Imported	Exporters	Exported
World	4,484,843	World	4,300,247
EU 27 & UK Aggregation	2,568,930	EU 27 & UK Aggregation	2,359,608
Bulgaria	415,221	Romania	669,108
Netherlands	296,048	France	512,871
Romania	292,515	Bulgaria	468,416
Spain	253,533	Hungary	226,627
Germany	235,576	Spain	74,291
France	218,903	Austria	73,612
Hungary	152,073	Slovakia	70,682
Austria	121,071	Italy	52,982
Czech Republic	101,772	Germany	48,747
Italy	92,383	Croatia	47,329

Source: ITC (2025).

Table 116 – Nutritional profile of sunflower meal used as raw material in aqua feeds

Nutrient	% Composition
Dry Matter (%)	92.2
Moisture (%)	7.8
Crude Protein (%)	35.2
Crude Lipids (%)	0.9
Crude Fibre (%)	19.6
Ash (%)	7.5
Gross Energy -MJ (MJ/kg)	16.9
Lysine (%)	1.2
Methionine (%)	0.8
Threonine (%)	1.2
Phosphorus (%)	0.8
Carbon Footprint (kg CO_2eq/t)	500.0

Based on sunflower meal, solvent extracted, 35% CP
Source: IAFFD (2025).

Table 117 – Evolution of market price (EUR/t) for sunflower meal

Material	2020	2021	2022	2023	2024
Sunflower meal ([175])	210	260	330	310	280

([175]) https://commodity-board.com/sunflower-meal-prices-decline-in-june-despite-record-export-levels/

Prices peaked in 2022, similar to other oilseed meals, due to global supply chain disruptions and high demand. In 2024, prices declined slightly, partly due to increased competition and changes in EU import duties.

10.6.2. Sunflower oil

Globally, the Russia leads sunflower oil production, accounting for 34% of global output with 6.82 Mt in 2024/2025, followed by Ukraine (5.29 Mt), EU (3.17 Mt) and Argentina (1.84 Mt) (Table 118; USDA, 2025b). Major EU producers including Bulgaria, Hungary, Romania and France (USDA, 2025b; EC, 2025) (Table 119; EC, 2025).

Trade is strong within the EU, with Spain, Italy and the Netherlands leading sunflower oil imports, while Bulgaria and Hungary are key exporters. This supply network supports the availability of sunflower derivatives for feed use across Europe (Table 119; ITC, 2025).

Table 118 – Top 10 worldwide sunflower oil producers by volume (Mt) (2024/25)

Trading Nation	% of Global Production	Total Production (million tonnes)
Russia	34.0	6.82
Ukraine	26.0	5.29
European Union	16.0	3.17
Argentina	9.0	1.84
Turkey	4.0	0.76
Kazakhstan	3.0	0.67
South Africa	1.0	0.28
Serbia	1.0	0.22
China	1.0	0.22
Bolivia	0.7	0.15

Source: USDA (2025b).

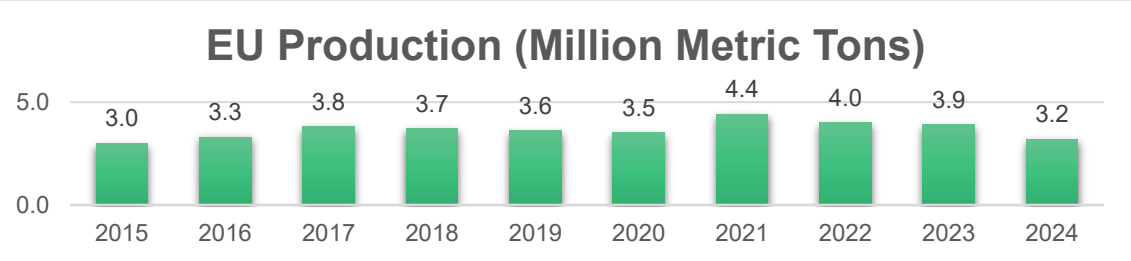
Table 119 – Top 10 EU sunflower oil producers by gross production (Mt) (2022)

EU Producers	EU Production (million tonnes)
Bulgaria	083
Hungary	0.73
Romania	0.60
France	0.59
Spain	0.48
Netherlands	0.21
Italy	0.16

EU Producers	EU Production (million tonnes)
Portugal	0.12
Czechia	0.10
Germany	0.09

Source: EC (2025a).

Figure 92 – Sunflower oil gross production by volume (Mt) for EU Member States and UK (2015-2024)



Source: EC (2025a).

Table 120 – Top 10 largest importers and exporters of sunflower oil in the EU and UK by value (‘000 EUR) in 2024

Importers	Imported	Exporters	Exported
World	12,544,659	World	11,322,797
EU 27 & UK Aggregation	4,293,965	EU 27 & UK Aggregation	2,175,326
Spain	839,271	Netherlands	552,891
Italy	681,880	Bulgaria	385,269
Netherlands	607,261	Hungary	374,577
Belgium	479,697	France	256,465
Poland	317,024	Poland	226,543
Germany	311,086	Romania	141,319
Bulgaria	297,346	Spain	65,862
France	253,726	Estonia	51,998
United Kingdom	123,801	Czech Republic	46,236
Portugal	66,555	Belgium	20,433

Source: ITC (2025).

Table 121 – Nutritional profile of sunflower oil used as raw material in aqua feeds

Nutrient	% Composition
Palmitic 16:0 (%)	6.3
Stearic 18:0 (%)	5.0
Oleic 18:1 n-9 (%)	22.4
Linoleic 18:2 n-6 (%)	65.7
Linolenic 18:3 n-3 (%)	0.1

Nutrient	% Composition
Arachidonic 20:4 n-6 (%)	0.0
EPA 20:5 n-3 (%)	0.0
DHA 22:6 n-3 (%)	0.0
EPA+DHA (%)	0.0
SAFA (%)	10.6
MUFA (%)	19.5
PUFA (%)	65.7
Sum n-3 (%)	0.1
Sum n-6 (%)	73.0
Phospholipids (%)	1.0
Carbon Footprint (kg CO2eq/t)	2,100.0

Source: IAFFD (2025).

Table 122 – Evolution of market price (EUR/t) for sunflower oil.

Material	2020	2021	2022	2023	2024
Sunflower oil [1]	1,056	1,719	1,934	1,218	1,270

[1]: https://tradingeconomics.com/commodity/sunflower-oil

The price of sunflower oil has experienced fluctuations over the past five years. In 2020, the price stood at approximately USD 1,056.51/t. However, by 2022, the price had surged to USD 1,934.16/t, as reported by the National Sunflower Association. In 2024, prices were around USD 1,270.17/t. Currently, in mid-2025, prices are approximately USD 1,456.69/t. In Ukraine, which accounts for over 70% of global sunflower oil exports, parched southern fields have resulted in a 11% reduction in crushing volumes in June and a 21% year-on-year decline. This has led to an increase in Black Sea FOB export quotes by USD 10–20/t, reaching approximately USD 1,110–1,120/t. Consequently, EU DAP interest has risen into the USD 1,160–1,200 range. Simultaneously, the rally in palm oil has curtailed Southeast Asian exports and redirected importers. India has also increased its sunflower oil purchases by 18% in June, reaching 216 kt, further tightening the market. With global sunflower seed output at a four-year low of approximately 50 Mt, processors are engaged in aggressive buying, fearing a subdued new harvest.

10.7. Palm oil

Globally, Indonesia (46.0 Mt) and Malaysia (19.4 Mt) dominate palm oil production, jointly accounting for over 80% of global supply in 2024/2025 (Table 123; USDA, 2025b). Other significant producers include Thailand (3.3 Mt), Colombia (1.9 Mt), and Nigeria (1.5 Mt) (USDA, 2025b).

Importantly, there is no production of palm oil in the EU (USDA, 2025b), making the EU fully dependent on imports for industrial and feed applications. As a result, the EU imported EUR 6.3 billion worth of palm oil in 2024, with the Netherlands (EUR 1.42 billion), Italy (EUR1.07 billion), and Germany (EUR 0.79 billion) being the top importers (Table 124; ITC, 2025). While EU exports totalled EUR 2.38 billion, these were mostly re-exports of imported palm oil (ITC, 2025).

Table 123 – Top 10 worldwide palm oil producers by volume (Mt) (2024/25)

Market	% of Global Production	Total Production (million tonnes)
Indonesia	58.0	46.0
Malaysia	25.0	19.4
Thailand	4.0	3.3
Colombia	2.0	1.9
Nigeria	2.0	1.5
Guatemala	1.0	1.0
Papua New Guinea	1.0	0.8
Brazil	0.8	0.6
Cote d'Ivoire	0.8	0.6
Honduras	0.8	0.6

Source: USDA (2025b).

Table 124 – Top 10 largest importers and exporters of palm oil in the EU and UK by value (‘000 EUR) in 2024

Importers	Imported	Exporters	Exported
World	39,159,319	World	38,222,117
EU 27 & UK Aggregation	6,299,922	EU 27 & UK Aggregation	2,377,180
Netherlands	1,418,089	Netherlands	1,083,909
Italy	1,074,746	Italy	290,177
Germany	793,644	Estonia	262,043
Spain	624,844	Germany	259,366
United Kingdom	417,933	Denmark	136,049
Belgium	346,286	Spain	125,346
Poland	317,105	Belgium	71,835
Denmark	213,013	Sweden	55,612
France	184,744	United Kingdom	34,077
Estonia	184,104	Austria	19,372

Source: ITC (2025).

Table 125 – Nutritional profile of palm oil used as raw material in aqua feeds

Nutrient	% Composition
Palmitic 16:0 (%)	44.1
Stearic 18:0 (%)	4.4
Oleic 18:1 n-9 (%)	39.0
Linoleic 18:2 n-6 (%)	9.1
Linolenic 18:3 n-3 (%)	0.2
Arachidonic 20:4 n-6 (%)	0.0
EPA 20:5 n-3 (%)	0.0
DHA 22:6 n-3 (%)	0.0
EPA+DHA (%)	0.0
SAFA (%)	51.6
MUFA (%)	37.0
PUFA (%)	9.5
Sum n-3 (%)	0.2
Sum n-6 (%)	10.1
Phospholipids (%)	1.1
Carbon Footprint (kg CO2eq/t)	1,700.0

Source: IAFFD (2025).

Table 126 – Evolution of market price (EUR/t) for palm oil

Material	2020	2021	2022	2023	2024
Palm oil (feed grade)([176]) [1]	675	1,000	1,600	900	1,050

Prices peaked in 2022 due to global supply chain disruptions, climate impacts, and biofuel competition. Prices have since stabilised but remain volatile.

10.8. Lupins

Global lupin production is dominated by Australia, which accounts for 67% of the world’s supply (1.28 Mt in 2023/2024), followed by the EU (19%) (Table 127). Within Europe, Poland (275.3 kt) and Germany (45.5 kt) are the largest producers (USDA, 2025b; EC, 2025) (Table 128).

Due to its limited global trade profile, lupin does not have a dedicated category in the ITC database, and detailed EU trade statistics are unavailable. However,

([176]) IndexBox Report on EU Palm Oil Market (2025 Edition) -https://www.indexbox.io/blog/palm-oil-european-union-market-overview-2024-1/ 2) IISD Global Market Report: Palm Oil Prices and Sustainability (2023) - https://www.iisd.org/system/files/2023-06/2023-global-market-report-palm-oil.pdf 3) Virtue Market Research – Europe Palm Oil Market Report (2024–2030) - https://virtuemarketresearch.com/report/europe-palm-oil-market

its production in Central and Eastern Europe supports regional sourcing for aquafeed producers.

Table 127 – Top 10 worldwide lupin producers by volume (kt) (2023/24)

Market	% of Global Production	Total Production (thousand tonnes)
Australia	67	1,279.7
European Union (27)	19	370.2
Poland	14	275.3
Russian Federation	7	136.4
Morocco	3	57.9
Germany	2	45.5
Chile	2	32.6
Greece	1	17.5
Peru	1	16.3
South Africa	1	16.0

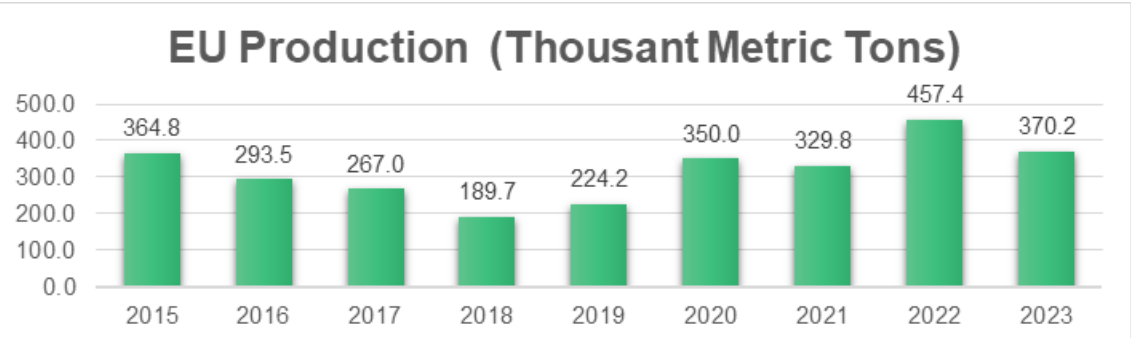
Source: FAO (2025b); USDA (2025b).

Table 128 – Top 10 EU lupin producers by gross production (kt) (2023/24)

EU Producers	EU Production (thousand tonnes)
Poland	275.32
Germany	45.50
Greece	17.45
France	10.87
Lithuania	4.59
Spain	1.88
Czechia	1.82
Italy	1.12
Austria	0.96

Source: FAO (2025b).

Figure 93 – Lupin production by volume (kt) by EU Member States and UK (2015-2024)



Source: EC (2025a).

Table 129 – Nutritional profile of lupins used as raw material in aqua feeds

Nutrient	% Composition
Dry Matter (%)	91.3
Moisture (%)	8.8
Crude Protein (%)	36.3
Crude Lipids (%)	7.4
Crude Fibre (%)	7.6
Ash (%)	3.7
Gross Energy -MJ (MJ/kg)	18.9
Lysine (%)	1.8
Methionine (%)	0.3
Threonine (%)	1.2
Phosphorus (%)	0.5
Carbon Footprint (kg CO_2eq/t)	1,000.0

Based on Lupin seed meal, 36% CP *Source*: IAFFD (2025)

Table 130 – Evolution of market price (EUR/t) for lupins

Material	2020	2021	2022	2023	2024
Lupins ([177])	280	310	370	340	320

Lupins are used as a protein-rich alternative to soybean meal in livestock feed and increasingly in plant-based food products. Prices peaked in 2022, in line with other protein crops, due to input cost inflation and supply chain disruptions. The market remains regionally variable, with higher prices in areas where lupins are grown organically or for food-grade use.

10.9. Faba beans

Europe is a major faba bean producer, accounting for 19% of global output in 2024/2025, alongside Ethiopia and China (USDA, 2025b) (Table 131). Key EU producers include France (216 kt), Lithuania (191 kt), and Germany (175 kt), with steady production increases observed over the past decade (Source: FAO (2025b).

Table 132). The UK, although no longer in the EU, remains a leading producer, accounting for approximately 30% of Europe’s faba bean market share in 2024.

In 2024, the EU exported EUR 75.4 million worth of faba beans and imported EUR 71.2 million, with France and Denmark among the top exporters and the

([177]) https://agridata.ec.europa.eu/extensions/DataPortal/prices.html; https://agriculture.ec.europa.eu/data-and-analysis/markets/price-data_en; https://www.wm-strategy.com/europe-lupins-market

UK and Germany among the main importers (ITC, 2025). This active trade environment underscores both the supply potential and market demand inside and outside the EU. The carbon footprint of faba beans is estimated at 900 kg CO_2eq/t – moderate compared to other plant proteins and lower than animal, based materials (IAFFD, 2025). Their regional production and relatively stable prices (ranging from EUR 250 to EUR 340/t between 2020 and 2024) make them a viable, sustainable feed material for European aquaculture.

Table 131 – Top 10 worldwide faba beans producers by volume (Mt) (2024/25)

Market	% of Global Production	Total Production (million tonnes)
China	28	1.70
Ethiopia	19	1.16
European Union	19	1.16
United Kingdom	11	0.69
Australia	10	0.64
France	4	0.22
Lithuania	3	0.19
Sudan	3	0.18
Germany	3	0.18
Egypt	2	0.10

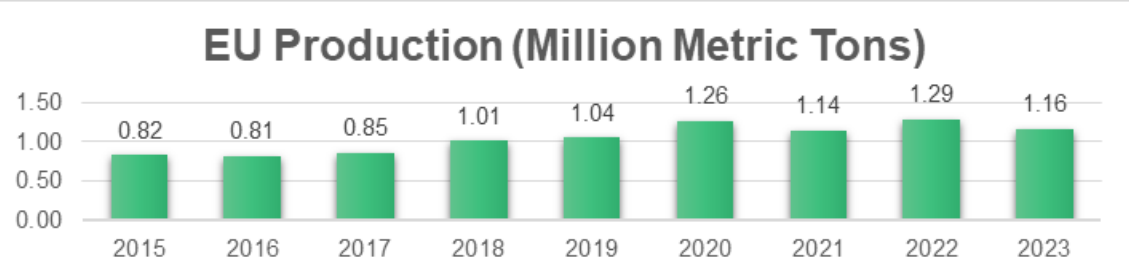
Source: FAO (2025b).

Table 132 – Top 10 EU faba beans producers by gross production (kt) (2023/24)

EU Producers	EU Production (thousand tonnes)
France	216.32
Lithuania	190.61
Germany	175.30
Italy	99.81
Poland	94.53
Denmark	74.23
Latvia	73.90
Ireland	72.41
Sweden	47.74
Spain	27.57

Source: FAO (2025b).

Figure 94 – Faba bean production by volume (Mt) by EU Member States (2015-2024)



Source: EC, 2025; FAO (2025b).

Table 133 – Top 10 EU importers and exporters of faba beans by value (‘000 EUR) (2024)

Importers	Imported	Exporters	Exported
World	606,356	World	568,124
EU 27 & UK Aggregation	101,703	EU 27 & UK Aggregation	208,428
Norway	70,659	Lithuania	43,577
Italy	16,017	Latvia	39,013
Netherlands	15,562	United Kingdom	29,828
Latvia	14,358	France	28,532
France	13,826	Denmark	23,622
Germany	8,837	Germany	10,931
United Kingdom	7,614	Netherlands	8,614
Denmark	7,197	Poland	8,300
Spain	5,496	Spain	4,630
Belgium	3,315	Estonia	4,418

Source: ITC (2025)

Table 134 – Nutritional profile of faba beans (dehulled) used as raw material in aqua feeds

Nutrient	% Composition
Dry Matter (%)	88.7
Moisture (%)	11.3
Crude Protein (%)	30.0
Crude Lipids (%)	1.6
Crude Fibre (%)	1.7
Ash (%)	3.0
Gross Energy -MJ (MJ/kg)	16.9
Lysine (%)	1.9
Methionine (%)	0.2
Threonine (%)	1.1
Phosphorus (%)	0.5
Carbon Footprint (kg CO_2eq/t)	900.0

Source: IAFFD, 2025

Table 135 - Evolution of market price (EUR/tonne) for faba beans

Material	2020	2021	2022	2023	2024
Faba beans ([178])	250	280	340	310	290

Faba beans are increasingly used as a local protein crop in the European feed and food sectors. Prices peaked in 2022, reflecting broader commodity inflation and increased demand for non-soy protein sources.

10.10. Peas

Globally, Russia and Canada lead dry pea production, contributing 46% of the total supply. The EU represents 14% of global production (1.9 Mt in 2023/2024), with France, Germany, and Spain being the largest producers (EC, 2025) (Table 136). EU production has steadily increased, driven by CAP incentives and consumer demand for sustainable, non-GMO protein alternatives.

Peas also feature in EU trade: in 2024, the EU exported EUR 75.4 million and imported EUR 71.2 million worth of peas and faba beans combined (ITC, 2025). France and Italy are prominent EU exporters, while the UK, Germany, and the Netherlands are key importers.

In terms of sustainability, carbon footprints vary significantly depending on the processing method and intensity. For instance, whole peas have a carbon footprint of approximately 300 kg CO_2eq/t, while concentrated protein isolates can have a carbon footprint of up to 1,900 kg CO_2eq/t (IAFFD, 2025). Price trends have followed broader market patterns, peaking at EUR 320/t in 2022 and stabilising at EUR 280/t in 2024 (VesperTool, 2025), reinforcing their role as a cost-effective protein alternative.

Table 136 – Top 10 worldwide peas producers by volume (Mt) (2023/2024)

Market	% of Global Production	Total Production (million tonnes)
Russia	27	3.7
Canada	19	2.6
European Union	14	1.9
China	11	1.5
India	8	1.1
United States	6	0.8
Ethiopia	3	0.4

([178]) https://www.mordorintelligence.com/industry-reports/fava-bean-market

Market	% of Global Production	Total Production (million tonnes)
Ukraine	3	0.4
Australia	2	0.3
United Kingdom	1	0.2

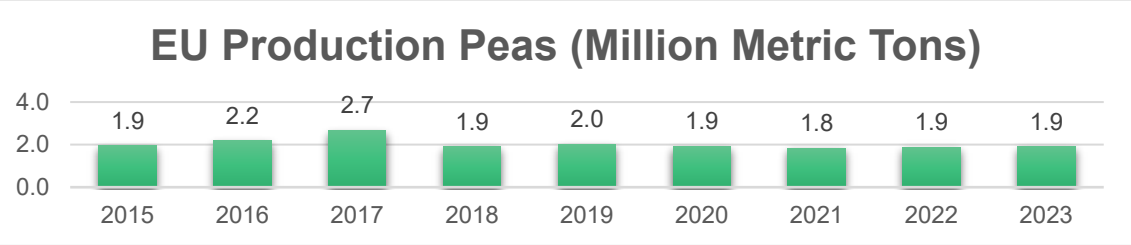
Source: FAO (2025b).; USDA, 2025b

Table 137 – Top 10 EU pea producers by volume (Mt) (2023-2024)

EU Producers	EU Production (million tonnes)
France	0.49
Germany	0.27
Spain	0.15
Romania	0.15
Lithuania	0.15
Czechia	0.11
Estonia	0.09
Finland	0.09
Poland	0.07
Latvia	0.07

Source: FAO (2025b).

Figure 95 – Pea production by volume (Mt) for EU and UK (2015-2024)



Source: EC, 2025; FAO (2025b).

Table 138 – Top 10 largest importers and exporters of peas by value (‘000 EUR) in the European Union and UK (2024)

Importers	Imported	Exporters	Exported
World	2,067,670	World	2,946,920
EU 27 & UK Aggregation	173,969	EU 27 & UK Aggregation	385,262
Italy	26,859	France	72,617
Germany	31,578	Lithuania	48,213
Norway	17,669	Latvia	38,680
Spain	10,637	Germany	35,651
Belgium	29,125	Estonia	30,860

Importers	Imported	Exporters	Exported
Netherlands	15,759	Hungary	27,987
France	8,838	Czech Republic	20,958
United Kingdom	16,264	Belgium	18,359
Latvia	923	Spain	18,205
Hungary	4,650	United Kingdom	14,141

Source: ITC, 2025

Table 139 - Nutritional profile of peas used as raw material in aqua feeds

Description	Pea protein concentrate	Pea seeds, shelled and extruded
Dry Matter (%)	90.2	89.9
Moisture (%)	9.8	10.1
Crude Protein (%)	54.4	24.3
Crude Lipids (%)	1.7	1.2
Crude Fibre (%)	0.0	6.5
Ash (%)	7.3	3.2
Gross Energy -MJ (MJ/kg)	18.1	16.6
Lysine (%)	4.8	1.4
Methionine (%)	0.8	0.2
Threonine (%)	2.0	0.9
Phosphorus (%)	0.8	0.4
Carbon Footprint (kg CO2eq/t)	1,900.0	300.0

Source: IAFFD, 2025

Table 140 - Evolution of market price (EUR/t) for peas ([179])

Material	2020	2021	2022	2023	2024
Peas	240	270	320	300	280
Pea protein concentrate (55%)	1,400	1,600	2,000	1,750	1,600

Pea prices followed a similar trend to other pulses, peaking in 2022. Pea protein concentrate (PPC) prices are much higher due to manufacturing costs and increased demand in plant-based food and feed markets. Prices for pea protein isolate (80% protein) are even higher, often surpassing EUR 2,200/t during peak years.

([179]) https://vespertool.com/food-materials/pea-protein/

10.11. Barley

The worldwide annual production of BSG has been estimated as approximately 38.6 billion tonnes in 2014.

Globally, the European Union is the leading barley producer, accounting for 35% of global production with 50.3 Mt in 2024/2025 (Table 141; USDA, 2025b). Other major producers include Russia (16.3 Mt), Australia (13.3 Mt), and Canada (8.1 Mt) (USDA, 2025b). Within the EU, Germany (10.6 Mt), France (9.9 Mt), and Spain (7.4 Mt) are the largest national producers (Table 142; EC, 2025).

Production trends from 2015 to 2025 show a relatively stable barley output across EU Member States, as illustrated in Figure 96 (EC, 2025). In trade, the EU imported barley worth EUR 2.36 billion and exported EUR 3.34 billion in 2024, highlighting its importance in regional feed and food markets (Table 143; ITC, 2025). Top importers included the Netherlands, Belgium, and Spain, while France, Germany, and Romania led exports within the EU (ITC, 2025).

Table 141 – Top 10 global barley producers by volume (Mt) (2024/25)

Market	% of Global Production	Total Production (million tonnes)
European Union	35	50.3
Russia	11	16.3
Australia	9	13.3
Canada	6	8.1
United Kingdom	5	7.1
Turkey	5	7.0
Ukraine	4	5.8
Argentina	3	4.9
Kazakhstan	3	3.8
United States	2	3.1

Source: USDA (2025b).

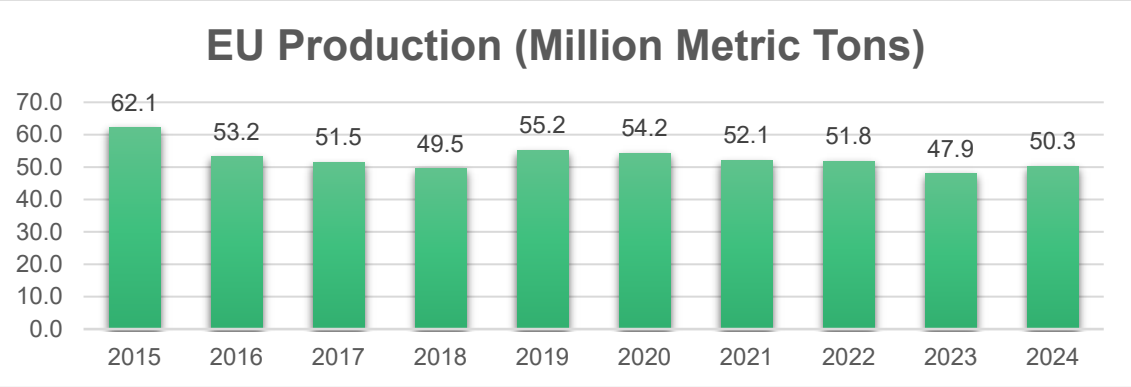
Table 142 – Top 10 EU MS barley producers by volume (Mt) (2024/25)

EU Producers	EU Production (million tonnes)
Germany	10.6
France	9.9
Spain	7.4
Denmark	3.2
Poland	3.0
Romania	2.7

EU Producers	EU Production (million tonnes)
Czechia	1.7
Hungary	1.6
Ireland	1.4
Sweden	1.3

Source: FAO (2025b).

Figure 96 – Barley production by volume (Mt) for EU and UK (2015-2024)



Source: EC, 2025b; USDA, 2025b

Table 143 - Top 10 largest importers and exporters of barley by value (‘000 EUR) (2024)

Importers	Imported	Exporters	Exported
World	8,844,899	World	7,857,872
EU 27 & UK Aggregation	2,361,346	EU 27 & UK Aggregation	3,335,230
Netherlands	550,547	France	1,273,668
Belgium	407,197	Germany	635,438
Spain	328,297	Romania	454,462
Germany	303,754	Hungary	171,005
Italy	143,525	United Kingdom	160,953
Portugal	110,009	Bulgaria	156,737
Ireland	102,057	Czech Republic	83,451
Denmark	67,835	Denmark	79,714
Austria	54,344	Lithuania	53,541
Romania	51,332	Poland	47,445

Source: ITC, 2025

Table 144 – Nutritional profile of barley used as raw material in aqua feeds

Nutrient Composition	% Composition
Dry Matter (%)	91.8
Moisture (%)	8.3

Nutrient Composition	% Composition
Crude Protein (%)	26.1
Crude Lipids (%)	6.9
Crude Fibre (%)	15.8
Ash (%)	4.1
Gross Energy -MJ (MJ/kg)	18.1
Lysine (%)	0.8
Methionine (%)	0.6
Threonine (%)	1.0
Phosphorus (%)	0.7
Carbon Footprint (kg CO_2eq/t)	300.0

Source: IAFFD, 2025

Table 145 - Evolution of market price (EUR/t) for barley

Material	2020	2021	2022	2023	2024
Barley ([180])	180	210	260	240	220

Prices peaked in 2022, reflecting global grain market volatility and input cost inflation. In 2023, prices declined, with values ranging from EUR 272/t in January to EUR 212/t on 1 June 2023. Barley is widely used in the feed, brewing and food sectors, and its price is influenced by both domestic EU production and global grain markets.

10.12. Cotton seed meal

Globally, India (4.2 Mt), China (3.5 Mt), and Brazil (2.4 Mt) are the top producers of cottonseed meal, together accounting for 70% of global production in 2024/2025 (Table 146; USDA, 2025b). The European Union produces very little CSM but imports it for use in animal and aquafeed production (EC, 2025). Major importers in the EU include Italy (EUR 39.6 million), Spain (EUR 11.2 million), and Slovakia (EUR 3.8 million), while Greece and Italy lead in exports of processed or re-distributed CSM (Table 147; ITC, 2025).

Table 146 – Top 10 worldwide cottonseed meal producers by volume (Mt) (2024/25)

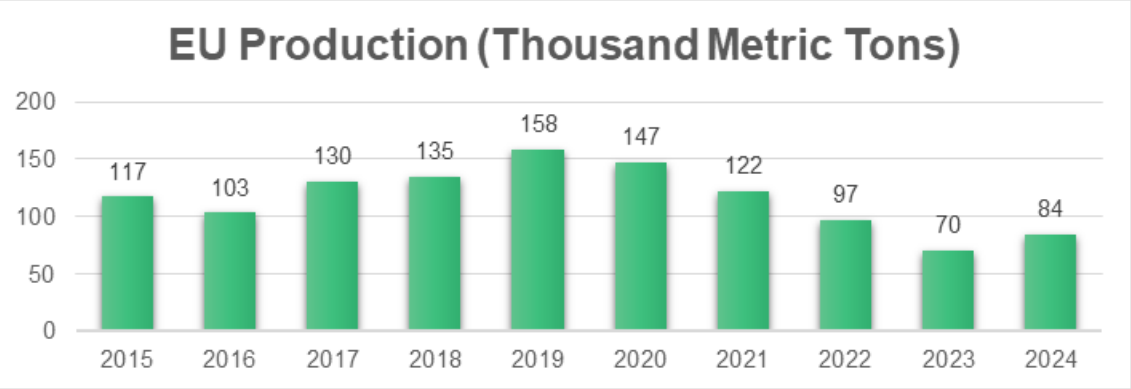
Market	% of Global Production	Total Production (million tonnes)
India	29	4.2
China	24	3.5
Brazil	17	2.4

([180]) https://www.procurementresource.com/resource-center/barley-price-trends

Market	% of Global Production	Total Production (million tonnes)
Pakistan	7	1.0
Turkey	5	0.7
United States	4	0.5
Uzbekistan	4	0.5
Mali	1	0.2
Turkmenistan	1	0.1
Benin	1	0.1

Source: USDA, 2025b

Figure 97 – Cottonseed meal production by volume (kt) for EU and UK (2015-2024)



Source: EC, 2025

Table 147 – Top 10 importers and exporters of cottonseed meal in the EU by value (‘000 EUR) (2024)

Importers	Imported	Exporters	Exported
World	449,318	World	450,835
EU 27 & UK Aggregation	58,216	EU 27 & UK Aggregation	68,430
Italy	39,564	Greece	65,145
Spain	11,167	Italy	1,451
Slovakia	3,790	Spain	900
Czech Republic	3,080	France	777
Romania	173	Slovakia	114
Portugal	104	Denmark	26
Greece	62	Bulgaria	6
Germany	52	Czech Republic	5
France	49	Romania	3
Belgium	42	Netherlands	2

Source: ITC, 2025

Table 148 - Nutritional profile of cottonseed meal used as raw material in aqua feeds

Nutrient Composition	% Composition
Dry Matter (%)	91.4
Moisture (%)	8.7
Crude Protein (%)	47.9
Crude Lipids (%)	1.7
Crude Fibre (%)	10.5
Ash (%)	6.6
Gross Energy (MJ/kg)	17.9
Lysine (%)	1.9
Methionine (%)	0.7
Threonine (%)	1.6
Phosphorus (%)	1.3
Carbon Footprint (kg CO2eq/t)	600.0

Based on cottonseed meal, 47% CP, solvent extracted (Source: IAFFD, 2025)

Table 149 – Evolution of market price (EUR/t) for cottonseed meal

Material	2020	2021	2022	2023	2024
Cottonseed ([181])	240	360	430	470	420

Cottonseed prices rose sharply between 2020 and 2023, with a peak around USD 511/t (~ EUR 470/t) in 2023. The price increase was driven by higher demand for cottonseed oil and meal, as well as global supply chain pressures. In 2024, prices declined slightly, reflecting improved supply and lower input costs.

10.13. Poultry by-products

The market for poultry by-products used in animal- and aquafeeds has expanded significantly in recent years, driven by the need for cost-effective, protein-rich alternatives to fishmeal, especially in emerging markets. In 2023, the global market value for poultry by-product meal intended for animal feed (including aquafeed) (excluding feather and blood components) was estimated at approximately USD 10.5 billion. By 2032, it is projected to reach USD 15.8 billion, reflecting a compound annual growth rate (CAGR) of 4.5% from 2024 onwards.

Within this broader category, several specialised protein materials are also experiencing rapid market growth. The global hydrolysed feather meal market is forecast to nearly double in size, from USD 589.5 million in 2025 to over USD

([181]) https://www.indexbox.io/blog/cottonseed-european-union-market-overview-2024-2/

1.27 billion by 2034, with a CAGR of 8.6%. Similarly, the poultry blood meal segment is projected to reach USD 1.9 billion by 2033, growing at an estimated CAGR of 6.2% between 2026 and 2033. These figures reflect the growing interest in circular economy solutions, where rendering and upcycling of animal by-products align with both sustainability and economic imperatives in aquafeed production.

From a pricing perspective, poultry by-product meal has remained a comparatively affordable protein source, especially when benchmarked against fishmeal. Over the 2020–2024 period, the price of feed-grade poultry by-product meal in Europe rose from EUR 395/t in 2020 to approximately EUR 694/t in 2024 (Table 150). The sharpest increases occurred in 2022 and 2023, linked to input cost inflation and global supply chain pressures. Nevertheless, the price trend has shown more stability than that of fishmeal, which is known for its volatility due to variable fish landings, climate conditions, and geopolitical events.

This relative price stability – combined with consistent availability and high protein digestibility – enhances the attractiveness of poultry by-products in aquafeed formulations. Their inclusion supports the industry's transition towards greater resource efficiency, while helping producers manage feed costs without compromising nutritional performance.

The market size projections and price data presented above are based on estimates from private consulting firms and industry sources. These figures should be treated as indicative only, as there are currently no official or standardised statistics from international bodies such as FAO or OECD that directly report on the trade volumes or market value of individual rendered animal proteins used in aquafeeds.

Table 150 – Evolution of market price (EUR/t) for Poultry by-products

Material	2020	2021	2022	2023	2024
Poultry by-product Meal, feed grade ([182])	395	423	553	615*	694*

The following Tables summarise the Top 10 chicken meat producers worldwide and, in the EU, and by extrapolation the Top 10 HFM producers.

Table 151 – Top 10 worldwide chicken meat producers by volume (Mt) (2024/25)

Market	% of Global Production	Total Production (million tonnes)
United States	21,0	21.34

([182]) Price from Hammersmith. https://hammersmithltd.blogspot.com. (*) prices estimated from previous years and https://marketmindsadvisory.com/poultry-meal-market-trends-growth/

Market	% of Global Production	Total Production (million tonnes)
China	15,0	15.35
Brazil	14,0	15.00
European Union	11,0	11.49
Russia	5,0	4.91
Mexico	4,0	3.99
Thailand	3,0	3.49
Turkey	2,0	2.51
Argentina	2,0	2.49
Colombia	2,0	1.91

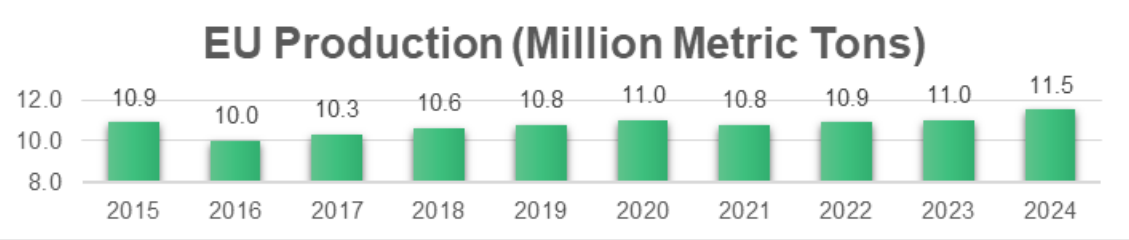
Source: USDA, 2025b

Table 152 - Top 10 EU chicken meat producers by gross production (Mt) (2024/25)

EU Producers	EU Production (million tonnes)
Poland	2.3
Spain	1.4
France	1.1
Germany	1.1
Italy	1.1
Netherlands	0.8
Romania	0.5
Belgium	0.4
Hungary	0.4
Portugal	0.3

Source: EC, 2025

Figure 98 – Chicken meat production by volume (Mt) for EU and UK (2015-2024)



Source: EC, 2025

Table 153 – Top 10 largest importers and exporters of chicken meat in the EU by value (‘000 EUR) in 2024

Importers	Imported	Exporters	Exported
World	1,153,097	World	1,121,002
EU 27 & UK Aggregation	741,946	EU 27 & UK Aggregation	746,315
Germany	167,008	Poland	104,436
United Kingdom	157,994	Italy	101,754
France	87,439	Belgium	87,707
Czech Republic	36,333	Austria	85,267
Spain	29,820	Netherlands	82,700
Belgium	29,168	France	81,456
Bulgaria	28,230	Spain	58,064
Greece	26,591	Greece	35,209
Netherlands	26,064	Portugal	23,791
Italy	21,808	Bulgaria	19,124

Source: ITC, 2025

Table 154 - Nutritional profile of poultry by-products used as raw material in aqua feeds

Description	Blood meal, spray dried, poultry, 90% CP	Feather meal, 81% CP	Poultry by-product meal, feed-grade, 60% CP	Hydrolysed poultry protein concentrate, dried
Dry Matter (%)	97.2	95.3	92.6	94.0
Moisture (%)	2.8	4.7	7.4	6.0
Crude Protein (%)	90.2	80.9	60.0	72.0
Crude Lipids (%)	1.0	9.7	12.4	6.8
Crude Fibre (%)	0.0	0.9	2.6	0.0
Ash (%)	4.4	1.9	15.3	14.5
Gross Energy -MJ (MJ/kg)	22.0	23.4	19.8	19.8
Lysine (%)	8.1	2.9	5.2	5.4
Methionine (%)	0.9	0.9	1.4	1.8
Threonine (%)	4.3	3.8	2.1	3.3
Phosphorus (%)	0.4	0.5	3.4	3.2
Carbon Footprint (kg CO_2eq/t)	1,000.0	600.0	700.0	700.0

Source: IAFFD, 2025

10.14. Pork (porcine) by-products

The global market for meat and bone meal (MBM) – including by-products such as poultry by-product meal and porcine meal – is expected to continue growing steadily. According to market projections, the MBM sector may reach a global value of approximately USD 6.23 billion by 2025, reflecting a compound annual growth rate (CAGR) of 4.7% from 2024. This trend is largely driven by rising demand for high-protein animal feed materials – particularly in emerging economies – and the growing emphasis on circular economy principles and sustainable utilisation of slaughterhouse by-products.

The market for porcine blood-derived products – such as plasma and haemoglobin – is also experiencing notable growth, fuelled by increasing demand in animal nutrition and other industrial applications. The global porcine plasma feed market is projected to reach USD 1.88 billion by 2031, reflecting a compound annual growth rate (CAGR) of 5.5%. Likewise, the European market for porcine haemoglobin is expected to reach approximately USD 223.2 million by 2033 – with a forecast CAGR of 6.0%.

However, it is important to emphasise that these estimates remain indicative. Market sizing is typically provided by private market intelligence firms using proprietary models and assumptions. As of mid-2025, no detailed, verifiable data on porcine by-products-based feed material production or trade volume is available from public sources such as the FAO, OECD or Eurostat. Consequently, while private projections can help illustrate market dynamics, they should be interpreted with caution and treated as directional rather than definitive.

Porcine meat and bone meal (PMBM) continues to offer a highly cost-effective alternative to fishmeal in aquafeeds. Between 2020 and 2024, PMBM prices rose gradually, from around EUR 220–260/tonne in 2020 to EUR 310–390/t in 2024. The initial increase in 2020–2021 was largely driven by disruptions caused by the COVID-19 pandemic and drought-related feed material shortages in South America. In 2022, prices rose more sharply due to the outbreak of the war in Ukraine and broader supply chain disruptions that affected the global trade in agricultural commodities. However, by 2023–2024, the market stabilised, and PMBM prices levelled off within a relatively narrow range.

Despite these increases, PMBM remains considerably cheaper than fishmeal, whose prices during the same period typically ranged from EUR 1,200/t to EUR 1,800/t. Furthermore, PMBM demonstrates greater price stability. Unlike fishmeal, which is subject to pronounced fluctuations due to variable wild fish landings, weather patterns, and geopolitical tensions, the supply of porcine by-products is continuous and more predictable. This makes PMBM a financially

resilient and strategically attractive component of modern aquafeed formulations.

Table 155 – Evolution of market price (EUR/tonne) for Porcine by-products

Material	2020	2021	2022	2023	2024
Meat and Bone Meal (MBM) of swine ([183])([184])([185])([186])	220–260	250–310	300–370	280–340	310–390

Table 156 – Top 10 worldwide swine meat producers by volume (Mt) (2024/25)

Market	% of Global Production	Total Production (million tonnes)
China	49,0%	57.06
European Union	18,0%	21.25
United States	11,0%	12.61
Brazil	4,0%	4.50
Russia	4,0%	4.32
Vietnam	3,0%	3.79
Canada	2,0%	2.09
Mexico	1,0%	1.59
South Korea	1,0%	1.46
Japan	1,0%	1.29

Source: USDA, 2025b

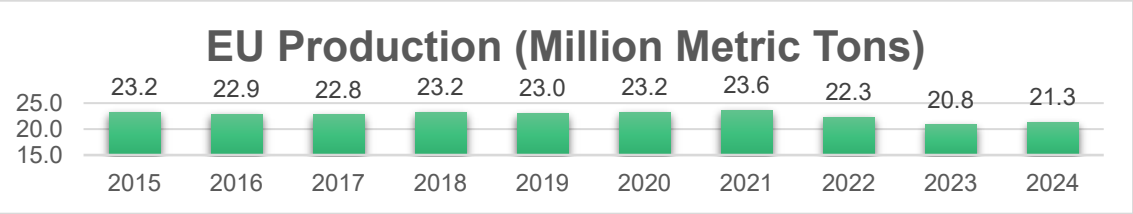
Table 157 – Top 10 EU swine meat producers by gross production (Mt) (2024/25)

EU Producers	EU Production (million tonnes)
Spain	4.9
Germany	4.2
France	2.1
Poland	1.8
Netherlands	1.5
Denmark	1.3
Italy	1.2
Belgium	0.9
Austria	0.5
Hungary	0.4

([183]) See: https://openknowledge.fao.org/server/api/core/bitstreams/09e88a46-b005-4d65-8753-9714506afc38/content
([184]) https://openknowledge.fao.org/server/api/core/bitstreams/09e88a46-b005-4d65-8753-9714506afc38/content
([185]) https://dir.tridge.com/market-insights/product/meat-and-bone-meal-mbm
([186]) https://www.indexbox.io/blog/processed-meat-european-union-market-overview-2024-7/

Source: EC, 2025

Figure 99 – Swine meat gross production by volume (Mt) for EU Member States and UK (2015-2024)



Source: EC, 2025b

Table 158 – Top 10 largest importers and exporters of swine meat in the EU and UK by value (‘000 EUR) in 2024

Importers	Imported	Exporters	Exported
World	2,622,521	World	2,427,647
EU 27 & UK Aggregation	2,463,583	EU 27 & UK Aggregation	2,309,410
Germany	716,919	Belgium	820,826
Italy	399,773	Germany	420,196
Poland	339,542	Netherlands	259,631
Greece	171,433	France	180,052
Romania	148,342	Denmark	166,757
Netherlands	112,818	Hungary	119,667
Austria	93,103	Poland	79,829
Slovakia	86,945	United Kingdom	62,852
Czech Republic	83,194	Spain	54,773
United Kingdom	41,735	Czech Republic	33,840

Source: ITC (2025).

Table 159 – Nutritional profile of swine meat used as raw material in aqua feeds

Description	Haemoglobin powder, 92% CP	Meat and bone meal, 45% CP
Dry Matter (%)	96.5	93.5
Moisture (%)	3.5	6.5
Crude Protein (%)	92.0	45.3
Crude Lipids (%)	0.2	8.5
Crude Fibre (%)	0.0	2.5
Ash (%)	4.3	37.0
Gross Energy -MJ (MJ/kg)	21.8	14.5
Lysine (%)	8.3	3.1
Methionine (%)	0.6	0.8
Threonine (%)	2.8	1.5

Description	Haemoglobin powder, 92% CP	Meat and bone meal, 45% CP
Phosphorus (%)	0.3	5.1
Carbon Footprint (kg CO_2eq/t)	900.0	500.0

Source: IAFFD (2025).

10.15. Porcine and poultry fat by-products

Currently, only 1.6% of the animal fats and meat by-products generated in the EU are used in aquaculture (EFPRA, 2021) – indicating significant untapped potential. With increasing pressure to develop sustainable, cost-efficient feed solutions, animal fats – especially poultry fat – represent a promising component of future aquafeed strategies.

The global market for edible animal fats was valued at USD 51.10 billion in 2023 and is projected to reach USD 75.92 billion by 2032, reflecting a compound annual growth rate (CAGR) of 4.4%. Within this total, the poultry fat segment alone was valued at USD 1.67 billion in 2023, with a forecasted increase to USD 2.89 billion by 2032 and a higher CAGR of 6.3%. It must be noted, however, that these figures derive from private market research reports, and their accuracy is non-verifiable due to the absence of consistent public data. Moreover, no distinction is made between edible fats and those destined for feed use, including aquafeeds – a critical limitation when interpreting their relevance for the aquaculture sector.

Across the European Union, approximately 18 million metric tonnes of animal fats and meat by-products are generated annually from slaughterhouses, dairies, and food processing plants (EFPRA, 2025). Rather than being discarded, many of these materials are responsibly recycled into feed materials – a practice that contributes to resource efficiency and the circular bioeconomy. Poultry fat, in particular, is a commonly used, energy-dense, and economically viable lipid source in commercial aquafeed formulations.

Despite their prevalence, official global trade statistics are lacking. For example, searches using HS codes 1501 00 (pig and poultry fats) and 1502 00 (fats of bovine animals) yield no meaningful results in the UN CoMTrade database. According to data from EFPRA, however, around 1.5 Mt of rendered animal fats are produced annually from EU slaughterhouses. The composition of these fat streams is roughly: 62% pork lard, 34% beef tallow, and 4% fish oils (Jedrejek *et al*., 2016).

In terms of pricing, wholesale prices for pork and beef fats currently range from USD 1.20 to 2.62/kg and USD 3.27 to 3.96/kg, respectively. This is still considerably lower than fish oil, which is priced at approximately USD 5.23/kg (Tridge, 2025). This price differential, along with stable supply, is a key driver

behind growing interest in terrestrial fats. However, price alone does not determine suitability.

Table 160 – Nutritional profile of terrestrial fats used as raw materials in aqua feeds

Description	Pork fat	Tallow, beef
Palmitic 16:0 (%)	19.9	0.9
Stearic 18:0 (%)	6.1	0.3
Oleic 18:1 n-9 (%)	15.7	2.4
Linoleic 18:2 n-6 (%)	11.9	3.1
Linolenic 18:3 n-3 (%)	0.6	0.6
Arachidonic 20:4 n-6 (%)	0.2	0.1
EPA 20:5 n-3 (%)	0.0	0.0
DHA 22:6 n-3 (%)	0.0	0.0
EPA+DHA (%)	0.0	0.0
SAFA (%)	41.1	52.1
MUFA (%)	44.9	40.5
PUFA (%)	11.2	3.7
Sum n-3 (%)	0.6	0.7
Sum n-6 (%)	13.5	3.6
Phospholipids (%)	9.9	9.9
Carbon Footprint (kg CO2eq/t)	1,100.0	1,500.0

Source: IAFFD (2025).

10.16. Single cell materials

Global production volumes of single cell materials are difficult to assess given that MCPs are often not segregated on their origin (yeast/fungi or bacteria) and have multiple uses from pharmacology to biofuel production, but the most recent estimates, from 2014-2016 indicate global production volumes for different microbial proteins totalling approximately 3.1 Mt per year, including both food and feed (compared to approximately 330 Mt of conventional animal protein in that period) (Matassa *et al*., 2016).

As with other SCP sources, for yeast and fungi to become competitive with fishmeal and soy protein in aquafeeds, there is a need for additional investment in large-scale production and at affordable costs for feed manufacturers and fish farmers (Hua *et al*., 2019). Encouragingly, the European yeast industry is the world leader with a 35% share of world production amounting to approximately 1 Mt (Cofalec, 2023). In addition, more concerted efforts should be dedicated to reviewing the existing legislation to accommodate more yeasts that are found to be safe for fish, for the environment, and for human consumption of the final products. Feedback from the industry survey suggests that fungal SCP is rated

positively (gaining a score of 3.55) but is not widely understood. It has a lower respondent count compared to other fishmeal replacements, as well as comments such as “*Still under-researched in tropical species. Moderate performance so far; not widely tested in commercial Asian feeds. Limited data for high inclusion rates*” (despite reviews such as Agboola *et al* (2021) listing 33% of their cited trials using tropical species.

10.16.1. Yeast

Yeast biomass – particularly from species such as *Saccharomyces cerevisiae*, *Candida utilis*, *Cyberlindnera jadinii*, and *Kluyveromyces marxianus* – typically contains between 40% and 55% crude protein, making it nutritionally comparable to soybean meal, though still lower in protein than fishmeal (Agboola *et al*., 2021; Covert *et al*., 2025; Gokulakrishnan *et al*., 2022). In addition to protein, yeasts contain B-group vitamins, nucleotides, and essential trace minerals, which are particularly valuable when traditional protein sources become scarce or expensive (Jach *et al*., 2022).

The amino acid composition of yeasts is generally favourable but can be limiting in key essential amino acids such as methionine, lysine, arginine, and phenylalanine – especially for carnivorous species – necessitating careful diet formulation or supplementation (Agboola *et al*., 2021; Sultana *et al*., 2024; Covert *et al*., 2025). Nonetheless, yeast's overall amino acid balance supports its inclusion as a complementary protein source in aquafeeds.

Yeast products are used in aquaculture in various forms, including live yeast, inactivated dried yeast, and whole-cell biomass. One of the most common types is spent brewer’s yeast (SBY or BSY), a by-product of the brewing industry. Studies show that BSY can replace 30% to 80% of fishmeal in diets for a range of fish species without compromising growth performance or feed conversion efficiency (San Martin *et al*., 2020; Gokulakrishnan *et al*., 2022; Covert *et al*., 2025).

Beyond use as a primary protein source, yeast products also serve as functional feed additives. Derivatives such as yeast extracts, β-glucans, mannan oligosaccharides, and nucleotides are widely used as prebiotics, immunostimulants, or synbiotics to promote gut health and immunity (Kiron, 2012; Del Valle *et al*., 2023; Mahdy *et al*., 2022). These features make yeast especially valuable in low-fishmeal diets, where disease resistance might otherwise decrease.

Digestibility remains a critical factor for yeast-based materials. Raw yeast biomass can present limitations in nutrient availability due to cell wall components such as chitin and mannans. However, fermentation and enzymatic hydrolysis have been shown to enhance nutrient release and improve digestibility. In salmonids, the apparent protein digestibility coefficient

of processed BSY has reached values as high as 77.6% (Martin *et al*., 2020; Orellana *et al*., 2024; Siddik *et al*., 2024).

Table 161 - Nutritional profile of single cell proteins (bacterial and yeast) used as raw materials in aqua feeds

Description	Bacterial single cell protein, 53% CP	Yeast, Brewer's dried yeast, 45% CP
Dry Matter (%)	83.2	92.6
Moisture (%)	16.8	7.5
Crude Protein (%)	53.4	44.3
Crude Lipids (%)	0.4	1.9
Crude Fibre (%)	0.8	1.8
Ash (%)	15.4	5.8
Gross Energy -MJ (MJ/kg)	15.1	18.1
Lysine (%)	3.1	3.0
Methionine (%)	1.1	0.7
Threonine (%)	2.5	1.9
Phosphorus (%)	2.3	0.9
Carbon Footprint (kg CO_2eq/t)	1,000.0	1,000.0

Source: IAFFD, 2025

The global yeast market was valued at approximately USD 7.8 billion in 2024 and is forecast to grow steadily, reaching an estimated USD 13.9 billion by 2033. This represents a compound annual growth rate (CAGR) of 6.6% over the period 2025–2033. This expansion is driven by rising demand across multiple sectors, including food and beverages, bioethanol production, and functional feed materials in animal nutrition, all of which contribute to the growing interest in yeast-based products as sustainable and bioactive protein alternatives.

The yeast biomass market, a subsegment of the broader category of single cell proteins, has experienced similar momentum. Key drivers include increasing awareness of the health benefits associated with yeast-derived compounds and the growing shift toward natural, bio-based materials in both food and feed applications. This market trajectory reflects the rising role of yeast in supporting gut health, immunity, and feed efficiency in aquaculture systems.

Notably, the global spent brewer’s yeast (SBY) market – a major yeast source for aquafeeds – is also expanding. It is estimated to reach USD 1.68 billion in 2025 and is projected to grow to USD 2.29 billion by 2030, with a CAGR of 6.4%. SBY has garnered attention for its dual function as both a protein material and a source of functional compounds such as β-glucans and nucleotides, although its inclusion rate is currently limited by pricing and amino acid profile constraints.

Despite growing interest, one of the main barriers to the broader adoption of yeast products in aquafeeds is cost. Yeast-based materials, particularly those intended for feed, remain relatively expensive compared to conventional protein sources such as fishmeal or processed animal proteins. Over the past five years, average prices of feed-grade yeast have increased only modestly – from approximately EUR 1,000/tonne in 2020 to around EUR 1,100/tonne in 2024. While these changes reflect only slight inflation, the baseline price remains high in absolute terms, limiting the economic feasibility of using yeast at high inclusion rates in commercial aquafeed formulations.

The upward trend is mainly attributed to increased costs of energy and raw materials used in yeast production, combined with global supply chain disruptions linked to the COVID-19 pandemic and Russia’s unprovoked aggression against Ukraine. At the same time, competing demand from the food and biofuel sectors has further pressured prices, reinforcing the perception of yeast as a high-value but premium input in aquafeed production.

It is important to emphasise that these market figures and price estimations are based on projections from private market research firms. As of now, neither the FAO nor the OECD provide systematic, verified data on global volumes or market values for yeast-based feed materials. Accordingly, while these estimates provide useful orientation, they should be interpreted with caution and regarded as indicative rather than definitive.

Table 162 – Evolution of market price (EUR/t) for yeast products

Material	2020	2021	2022	2023	2024
Feed yeast ([187])([188])([189])([190])	1,000	1,020	1,050	1,080	1,100

10.16.2. Fungal proteins

The variability in the nutritional content of fungi due to substrate and culture conditions challenge the introduction of a standardized method for their application in fish feed. Furthermore, filamentous fungi may produce mycotoxins such as aflatoxin, ochratoxin, citrinin, and fusarin that can manifest in the fish feed without careful monitoring. In addition, a number of fungal species, including *Fusarium*, *Aspergillus*, *Exophiala*, *Scytalidium*, and *Mucor* have been isolated as opportunistic filamentous fungal pathogens from various fish species including Atlantic salmon and rainbow trout (Gozlan et al., 2014). These issues

([187]) Europe Yeast Market Report Size, Share, and Trends Analysis Report – Industry Overview and Forecast to 2032 | Data Bridge Market Research - https://www.databridgemarketresearch.com/reports/europe-yeast-market
([188]) European Commission – Agri-Food Data Portal - https://agridata.ec.europa.eu/extensions/DataPortal/prices.html
([189]) IndexBox – Europe: Bakers' and Active Yeast Market Report - https://www.indexbox.io/blog/active-yeast-europe-market-overview-2024-1/
([190]) Tridge – Global Yeast Prices - https://dir.tridge.com/prices/yeast

complicate the use of fungi and dissuade their wider adoption as aquafeed materials.

Fungal proteins are gaining attention as a sustainable alternative to traditional protein sources, including fishmeal, in aquafeeds. Derived from several species of fungi, these proteins are rich in essential amino acids (particularly lysine, which is sometimes deficient in plant-based proteins), making them a valuable material for aquaculture diets (Onomy & Okuthe, 2024). Additionally, fungal proteins can be produced using various substrates, including agricultural by-products, which contributes to waste reduction and resource efficiency in aquaculture (Makkar *et al*., 2016).

Despite their nutritional advantages, the use of fungal proteins in aquafeeds is still developing, and several challenges remain. The digestibility of fungal proteins can vary depending on the species and processing methods used, with some fungi containing cell wall components that may hinder nutrient absorption (Sultana *et al*., 2024). Research is ongoing to improve the digestibility of fungal protein sources through various processing techniques, such as fermentation and enzymatic treatments.

Aquatic species exhibit varying degrees of tolerance to fungal proteins. Many studies have shown positive growth performance in fish when diets are supplemented with fungal protein sources. Replacement of fishmeal has been achieved at levels of 50% in European seabass (Oliva-Teles and Goncalves, 2001), 20% in gilthead seabream (Fronte *et al*., 2019), 40% in rainbow trout (Vidakovic *et al*., 2020) and 24% in whiteleg shrimp (Guo *et al*., 2019).

Global production is difficult to assess given that MCPs are often not segregated on their origin (yeast/fungi or bacteria) and have multiple uses from pharmacology to biofuel production, but the most recent estimates - from 2014-2016 indicate global production volumes for different microbial proteins totalling approximately 3.1 Mt per year, including both food and feed (compared to approximately 330 Mt of conventional animal protein in that period) (Matassa *et al*., 2016).

The European Commission (EC) Regulation No 68/2013 on the catalogue of feed materials classified yeast under products obtained by fermentation using micro-organisms, but in which the micro-organisms have been inactivated before use as animal feed (Commission Regulation (EC) 2013). Currently under these guidelines, only inactivated *Saccharomyces cerevisiae* and *Cyberlindnera jadinii* among the yeast reviewed are allowed for use as macro-materials in feed within the EU. In contrast, three species that have shown potential within aquafeed research: *Kluyveromyces marxianus, Blastobotrys adeninivorans* and *Wickerhamomyces anomalus* are currently unauthorised for use as major feed sources in both the EU and the US. However, it is important to state that *K. marxianus* and *W. anomalus* are listed under qualified presumption of safety biological agents catalogue of European Food Safety Association and listing

them in the catalogue of feed material should not be an issue (Agboola *et al*., 2021).

As with other SCP sources, for yeast and fungi to become competitive with fishmeal and soy protein in aquafeeds, there is a need for additional investment in large-scale production at affordable prices for feed manufacturers and fish farmers (Hua *et al*., 2019). Encouragingly, the European yeast industry is the world leader with a 35% share of world production amounting to approximately 1 Mt (Cofalec, 2023). In addition, more concerted efforts should be dedicated at reviewing the existing legislations to accommodate more yeasts that are found to be safe for fish, for the environment and for human consumption of the final products. Feedback from the industry survey suggests that fungal SCP is rated positively (gaining a score of 3.55) but not widely understood. It has a lower respondent count compared to other fishmeal replacements, as well as comments such as “*Still under-researched in tropical species. Moderate performance so far; not widely tested in commercial Asian feeds. Limited data for high inclusion rates*” (despite reviews such as Agboola *et al*. (2021) listing 33% of their cited trials as using tropical species).

Table 163 – Evolution of market price (EUR/t) for single cell proteins: fungal protein

Material	2020	2021	2022	2023	2024
Fungal SCP (Feed Grade) ([191])	2,800	2,600	2,400	2,200	2,000

Prices have declined steadily due to technological improvements, scale-up of fermentation, and policy incentives. Fungal SCP remains more expensive than soybean meal but is becoming more competitive in high-value feed applications.

10.16.3. Bacteria

Hua *et al*. (2019) suggested that bacterial protein use is still limited due to the high cost of production, though this may be decreasing to levels that are competitive with fishmeal. A recent study, for example, found that SCP from emerging techniques can be produced below USD 1,600/kg (Li *et al*., 2024). Also, as with other SCP, regulations around the substrate used to grow bacteria can be restrictive. In the EU, the key regulatory frameworks governing these aspects include the General Food Law Regulation ([192]), which establishes the principles of food and feed safety, and the Feed Hygiene Regulation ([193]), which sets the requirements for feed production. Such regulations scrutinise the demonstration of the absence of toxic compounds originating from substrates,

([191]) InnoProtein Project – Horizon Europe - https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/projects-details/43108390/101112072/HORIZON 2) Statista – Protein Industry Overview - https://www.statista.com/topics/4232/protein-market/ 3) FAO – World Food and Agriculture Statistical Yearbook -https://www.fao.org/family-farming/detail/en/c/1725784/

([192]) *OJ L 31, 1.2.2002*, ELI: http://data.europa.eu/eli/reg/2002/178/oj

([193]) *OJ L 35, 8.2.2005*, ELI: http://data.europa.eu/eli/reg/2005/183/oj

biosynthesised by microorganisms, or formed during technological processes. Robust monitoring and testing protocols are mandated to consistently meet these safety standards, ensuring that SCP does not pose risks to either the animals consuming them or to the consumers of animal products. Thus, the feed and food legislation for SCP plays a pivotal role in shaping the trajectory of these innovative protein sources. Companies and researchers developing SCP must navigate the regulatory landscape, providing robust scientific evidence to support safety and efficacy while complying with applicable regulations. Governmental/EU support may encourage entrepreneurship, innovation and development in these areas.

Table 164 - Evolution of market price (EUR/t) for Single cell proteins: Bacterial protein.

Material	2020	2021	2022	2023	2024
Bacterial SCP (Feed Grade)([194])([195])([196])([197])	3,800	3,500	3,200	2,900	1,600 – 2,700

Prices have declined due to technological improvements, economies of scale, and regulatory support. Bacterial SCP remains more expensive than traditional feed proteins but is increasingly competitive in high-value feed applications.

10.17. Microalgae

The global production of Spirulina (which makes up 99,55% of FAO’s global microalgae production records), increased from 56,456 Mt in 2019 to 66,691 Mt in 2023 (FAO, 2025a). Hua *et al* (2019) calculated that current global microalgae production (for all uses) is only 0.7% of what would be needed to replace the protein from fish meal in aquaculture. The European algae sector accounts for 0.8% of global production.

Of particular interest and promise is the culture of microalgae using CO_2 emissions and/or providing the remediation of (nutrient rich) wastewater. However, these applications involve many regulatory aspects (wastewater quality standards, microbial safety, toxic substances, feed safety regulations, environmental impact assessment, labelling and documentation, approval and certification to name a few), reviewed by Vijayaram *et al*, (2024), which need to be considered to ensure both the safety of the aquafeed and the protection of the environment. However, the main barrier to increasing microalgae production in the EU was identified as the high-end technological equipment and substantial workforce needed to cultivate biomass, entailing high operational

([194]) InnoProtein Project – EU Horizon Europe -https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/opportunities/projects-details/43108390/101112072/HORIZON
[195] Calysta – FeedKind® Protein - https://calysta.com/
[196] Statista - https://www.statista.com/
[197] See Li *et al* (2024)

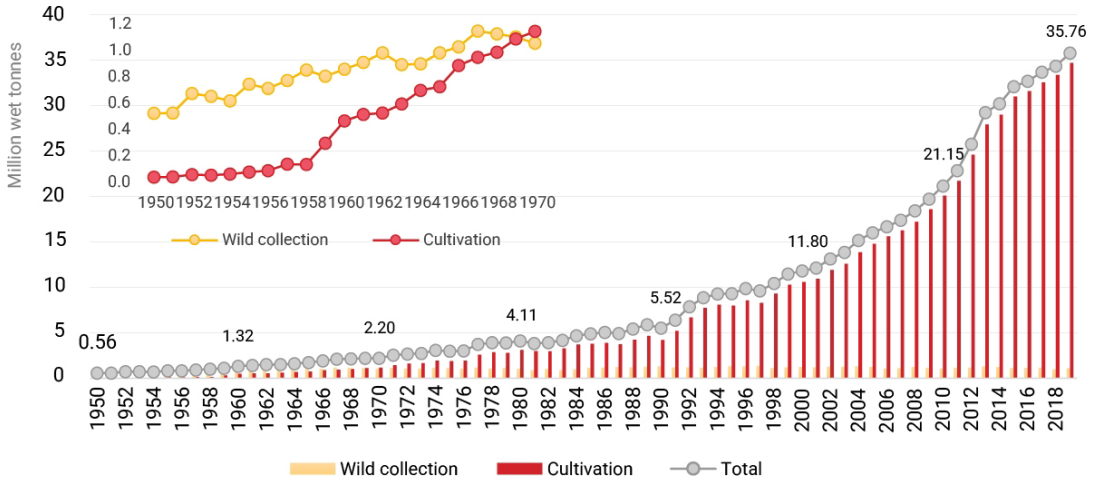
costs (Keuch, Breuer and Popescu, 2023). Presently, the production cost of Spirulina and Chlorella meal ranges from about USD 5/kg to USD 30/kg (Gao *et al*, 2024; Saadaoui *et al*, 2021), compared to fishmeal values of around USD 1.86/kg (Nunes *et al*., 2022). Thus, the price difference makes it impossible for fishmeal to be fully replaced by microalgal meals at present. However, recent advancements in culture technology have significantly decreased the production cost of microalgae – to as low as USD 1.07-1.6/kg rendering them more financially feasible (Ma and Hu, 2024).

10.18. Macroalgae

The production of marine macroalgae (also termed seaweeds) is an established industry that accounts for nearly 30% of global aquaculture production, with an output volume of 30 Mt per year that is worth more than USD 6 billion. Nearly 90% of all cultivated seaweeds are produced in China and Indonesia.

In a cost review of using Ulva at 10-15% inclusion in Atlantic Salmon diets, Wan *et al*. (2018) calculated the cost of production of Ulva to be EUR 108/t (compared to a concurrent price of EUR 1,418/t for fishmeal), resulting in a final cost of EUR 562-606/t compared to EUR 647/t in a standard diet.

Figure 100 – Status and trends of global seaweed production

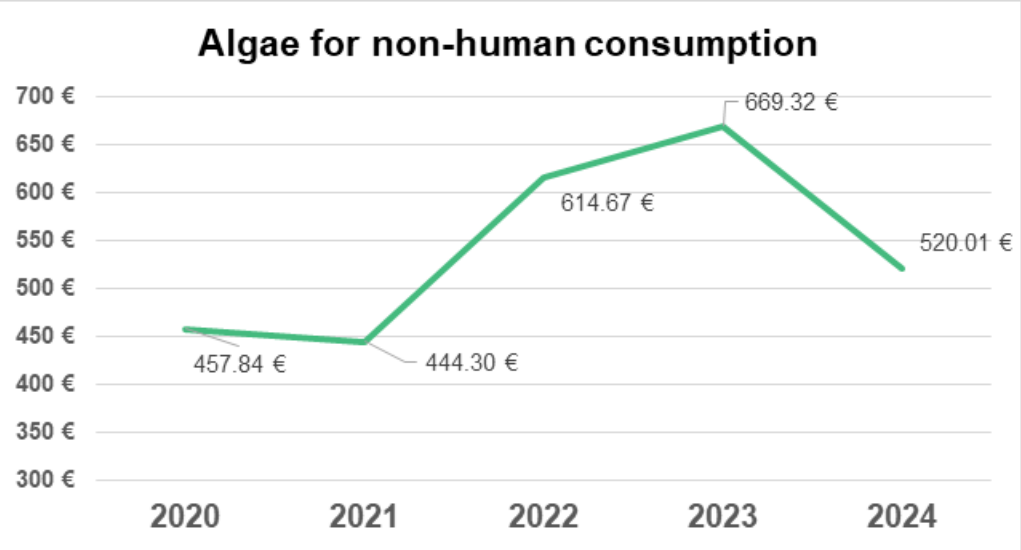


Source: FAO (2025c).

Restrictions on wider use might be due to regulatory measures.; Under the EU’s Catalogue of Feed Materials (EU Regulation 68/2013), seaweeds can be marketed using the term ‘seaweed meal’, if the product is derived from drying and crushing of macro-algae. However, beyond this, seaweeds which have been subjected to other manufacturing processes will fall under the remit of ‘novel feed material’ and are therefore subject to European Regulation (EC) 767/2009. Furthermore, depending on the claims made, seaweed product could be deemed as a ‘feed additive’ rather than a ‘feed material’, e.g. ‘favourably

affect the characteristics of animal product’ (2011/25/EU; EU, 2011). If seaweeds were to be deemed an additive, then the material would be legislated by Regulation 1831/2003, which requires authorisation from the European Food Safety Authority (EFSA) before products can enter the European market.

Figure 101 – Average price estimates of seaweed and other algae not for human use imported by EU Member States in the period 2020-2024



Source: EUMOFA (2025).

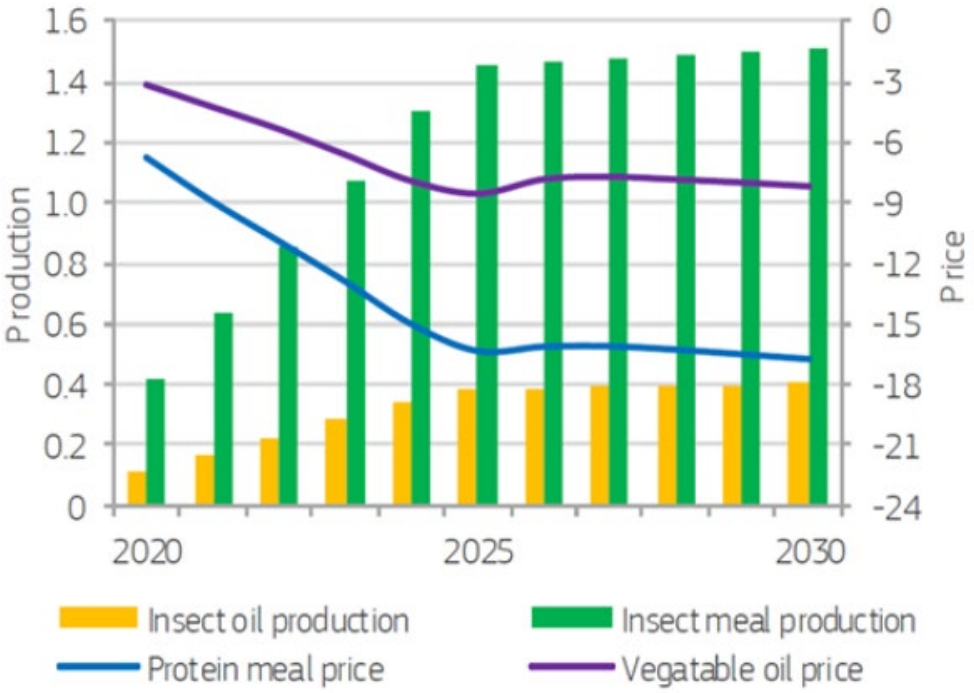
10.19. Insects

Wider use of insect meal by aquafeed companies may have been partially inhibited by concerns over customer acceptance (Rumbos *et al*., 2021), impacts on the product’s taste (Belghit *et al*, 2019), and variable/sub-optimal nutritional profile (Tran, 2015), However, by far the most pressing issues are supply limitations and cost. Production levels of insect meal are currently insufficient for constant supply, although global production is increasing.

According to the International Platform of Insects for Food and Feed (IPIFF) the volume of insect meal increased from 6,000 t in 2019 to 9,500 t in 2022 (IPIFF, 2019, 2023) and then to between 40,000 to 60,000 in 2026 (IPIFF, Personal Communication). Historically, the sector has been dominated by small and medium sized businesses which lack the stability and capacity required by aquafeed manufacturers, though the situation is improving; authorities report that several producers in Europe operate at >1,000 t of insect biomass per annum (IPIFF, 2023). The largest consumer of insect meal is the pet food industry which has a market share of around 40%, followed by the aquaculture market, which is expected to account for approximately 28% (den Hoorn, 2023), At 2026 production levels, that would equate to 11,200 t – 16,800 t; comparatively, the annual production of fishmeal used in aquaculture is

estimated to be 3,900,000 t (EC 2021). Even given predicted growth in production (Figure 102) supply is likely to remain an issue in the near future, though some predictions forecast an increase of 550% by 2032.

Figure 102 - EU insect meal and oil production (million MT) and producer price (%) - difference relative to baseline



Source: EC. 2020

Table 165 - Nutritional profile of yellow mealworm and black soldier fly larvae meal used as raw material in aqua feeds

Description	Yellow mealworm meal, defatted	Yellow Mealworm meal, full fat	Black soldier fly meal, defatted	Black soldier fly, Full-fat
Dry Matter (%)	93.0	96.4	97.5	96.0
Moisture (%)	7.0	3.6	2.5	4.0
Crude Protein (%)	65.0	59.5	56.1	35.4
Crude Lipids (%)	13.0	31.0	4.8	32.4
Crude Fibre (%)	12.0	2.0	3.0	0.0
Ash (%)	2.5	3.0	6.5	6.0
Gross Energy -MJ (MJ/kg)	22.5	26.6	20.2	24.8
Lysine (%)	5.0	3.4	3.2	1.5
Methionine (%)	1.5	0.8	0.9	0.3
Threonine (%)	2.5	2.5	2.3	1.5
Phosphorus (%)	0.6	0.6	1.0	1.1
Carbon Footprint (kg CO_2eq/t)	2000.0	2000.0	2000.0	2000.0

Source: IAFFD, 2025

Table 166 - Nutritional profile of BSF larvae oil used as raw material in aqua feeds

Description	BSF larvae oil
Palmitic 16:0 (%)	10.4
Stearic 18:0 (%)	2.0
Oleic 18:1 n-9 (%)	18.8
Linoleic 18:2 n-6 (%)	16.3
Linolenic 18:3 n-3 (%)	2.6
Arachidonic 20:4 n-6 (%)	0.0
EPA 20:5 n-3 (%)	0.0
DHA 22:6 n-3 (%)	0.0
EPA+DHA (%)	0.0
SAFA (%)	59.1
MUFA (%)	21.2
PUFA (%)	18.7
Sum n-3 (%)	2.9
Sum n-6 (%)	18.1
Phospholipids (%)	9.9
Carbon Footprint (kg CO_2eq/t)	3,000.0

Source: IAFFD, 2025

Regarding costs, until now, high prices for insects have kept feed and food producers from incorporating insects in their product formulations (Tavares *et al.*, 2022). The most generous costs of production of BSL have been estimated at USD 2.00/kg compared to fishmeal of around USD 1.86/kg (Nunes et al., 2022). Whilst the IPIFF suggests that, at scale, insect meal can be produced at around €3/kg.

In a comprehensive review of the insect meal market within Europe, van den Hoorn (2023) identified 10 issues that require support and facilitation to adequately develop production. This is reflected in the current report’s industry survey, which scored insect meal and oil as 3.54 and 3.13 respectively (out of a potential 5) in terms of potential for fishmeal replacement – concluding that, though popular and widely accepted, especially in Europe; scalability and perception are limiting factors. Specifically, an interviewed consultant commented “*Insect meal offers good amino acid profile and digestibility. [It is] suitable for partial replacement [but] still limited by cost and palatability at high inclusion levels. Most trials show comparable growth to fishmeal at 10–30% inclusion.* An Industry representative group stated*: “The EC needs to diversify its investment in alternatives. Too much money has been spent on insects without tangible return, and now we are seeing market failure of parts of that sector because it was over reliant on subsidies,* Ironically, while it is true that some insect protein plants have received farming subsidies in the past (Palmer,

2019), in van den Hoorn’s (2023) review, a lack of subsidy availability was found to be a barrier to future development.

Table 167 - Evolution of market price (€/MT) for insect meal products

Material	2020	2021	2022	2023	2024
Black soldier fly larvae, mealworms, and crickets [1] ([198])	3,500	3,200	2,000 – 2,800	2,600	2,400/ 3,800-6,000

Prices have declined steadily due to economies of scale, technological improvements, and regulatory support. Insect meal remains more expensive than traditional feed proteins (e.g., soybean meal), but the gap is narrowing.

10.20. Genetically modified materials

10.20.1. Genetically Modified (GM) or Improved Grain-Based Materials with Pest and Herbicide Tolerance and Reduced Anti-Nutritional Factors.

Soybean (*Glycine max*) is one of the most widely cultivated and economically important crops globally, serving as a major source of protein and oil for both human consumption and animal feed. However, its productivity is significantly threatened by biotic stressors, particularly insect pests and invasive weed species. These factors contribute to substantial yield losses each year, thereby reducing overall agricultural efficiency and food security. In response to these challenges, advances in genetic engineering have led to the development of genetically modified (GM) crop varieties with enhanced resistance traits. Notably, insect-resistant crops expressing *Bacillus thuringiensis* (Bt) toxins, such as Bt corn, and herbicide-tolerant crops like glyphosate-resistant soybeans, have been engineered to enable more precise and effective pest and weed management. These innovations have not only improved yield stability but also reduced the dependency on broad-spectrum chemical pesticides, contributing to more sustainable agricultural practices (Duke and Powles, 2009; James, 2014).

Soybean meal (SBM) is a widely used plant protein in aquafeeds, but it contains anti-nutritional factors (ANFs) such as trypsin inhibitors and oligosaccharides

([198]) FAO – Edible Insects: Future Prospects for Food and Feed Security - https://www.fao.org/fsnforum/resources/reports-and-briefs/edible-insects-future-prospects-food-and-feed-security; Statista – Edible Insects Statistics & Facts - https://www.statista.com/topics/4806/edible-insects/; FAO – Open Knowledge Repository on Edible Insects - https://openknowledge.fao.org/handle/20.500.14283/CD5077EN;

that can impair digestibility and health in aquatic species. Both genetically modified and conventionally bred soybean lines have been developed to reduce ANFs and improve amino acid profiles (Francis et al., 2001; Herman, 2003; Liu et al., 2025; Smith et al., 2025).

While many commercial soy varieties used in aquafeeds are non-GM, several breeding programs and partnerships—such as Corteva and Bunge—are developing GM soybeans tailored for aquaculture use.

Genetically modified (GM) crops, beyond soybeans, are being increasingly explored for use in aquafeeds to enhance insect and herbicide resistance, improve protein quality, enhance digestibility, modify lipid profiles, and increase resistance to environmental stressors. For example, GM maize (corn) has been developed a) for insect resistance (Bacillus toxin gene) with no negative impacts to Atlantic salmon (Sanden et al. 2006; Hemre et al., 2007) and b) expressing the phytase enzymes found to enhance phosphorus availability and has also been engineered separately to improve amino acid profiles, such as increasing lysine and methionine content (Hu et al., 2022). Additionally, GM alfalfa (lucerne), a high-protein forage crop, has been genetically modified to reduce lignin content, thereby improving its digestibility, while GM lupin was developed for increased production of methionine in seed (Glencross et al. 2003).

10.20.2. GM Oilseeds Producing Long-Chain Omega-3 Fatty Acids (EPA and DHA)

One of the most commercially advanced GM feed materials is Aquaterra® Omega-3 canola, developed by Nuseed and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). This GM canola has been engineered to biosynthesise eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), key omega-3 fatty acids typically derived from fish oil (Napier et al., 2023). The Norwegian Food Safety Authority (NFSA) approved the DHA-canola oil for use in salmon feed in Norway in 2023 and it is currently marketed across Europe and other global regions ([199]).

Safety and nutritional assessments have confirmed that Aquaterra is compositionally equivalent to conventional canola, except in its modified fatty acid profile. Commercial-scale trials conducted in Chile (2018–2019) and in Norway by Nofima demonstrated that inclusion rates of 1.5–1.9% led to

[199] SeafoodSource, July 2023; https://www.seafoodsource.com/news/aquaculture/aquaterra-s-omega-3-oil-gets-norwegian-approval-for-use-in-aquafeed

improved fillet omega-3 levels and lower diet-related mortality in farmed salmon ([200]).

From a sustainability perspective, one to two hectares of Aquaterra canola can produce as much DHA as approximately 10,000 kg of wild fish, offering a significant reduction in reliance on marine resources (SeafoodSource, 2023). The product is also recognised by sustainability schemes such as Friend of the Sea ([201]).

A GM variety of camelina that produces only EPA was successfully utilised as a substitute for fish oil in Atlantic salmon feeds, demonstrating comparable growth performance and maintaining muscle long-chain n-3 fatty acid levels without noticeable impacts on fish health or welfare (Betancor et al., 2015). Ruyter et al. (2019) examined a genetically modified n-3 canola oil (DHA-CA) that is high in docosahexaenoic acid (DHA). Their findings indicated that it fully substituted fish oil in the diets of juvenile (fingerling) Atlantic salmon, maintaining growth, survival, and tissue DHA levels without any compromise.

10.20.3. GM Microorganisms Producing Omega-3s

Genetically modified microorganisms have also been explored as alternatives to fish oil. In the early 2010s, DuPont, in partnership with AquaChile, developed a GM yeast strain capable of EPA production under the Verlasso brand. While initial feed trials showed promise in reducing fish oil dependency, the product encountered significant market resistance due to concerns related to GMOs, leading to a shift toward non-GMO formulations by 2019 (Sawitsky & Thompson, 2023). Metabolically engineered *Schizochytrium* spp., a genus of microalgae, is also under active development. Although most commercial omega-3 algal products currently rely on non-GM strains, research is underway to enhance fatty acid biosynthetic pathways through genetic engineering (Kumari et al. 2023). Despite these promising results, GM algal strains remain in the research and early commercialisation phase.

10.20.4. GM Insects (Research Phase)

Genetic engineering efforts are underway to improve the nutritional quality of black soldier fly (*Hermetia illucens*) larvae, a promising source of insect protein. Research focuses on enhancing protein content, achieving an optimal balance of essential amino acids, and optimising lipid profiles. However, as of mid-2025, no GM insect-derived feed materials have received regulatory approval for

[200] https://geneticliteracyproject.org/2021/03/23/heres-how-gm-canola-derived-fish-feed-could-make-aquaculture-more-sustainable/

[201] https://friendofthesea.org/certifies-aquaterra-for-sustainable-omega-3-oil/

commercial use in aquaculture. A biotechnological study by NARO (National Agriculture and Food Research Organization) and the University of Tokyo silenced the HiNATt amino-acid transporter gene in *Hermetia illucens* larvae. This led to a 1.8× increase in total amino acids and over a 2.5× increase in methionine and histidine levels, clearly demonstrating the feasibility of improving essential amino acid profiles via genetic manipulation (Liu et al., 2024).

10.21. Additives

Table 168 - Additives identified in commercial aquafeeds for the species and life-cycle stage of interest.

Additive Category		Seabream, Seabass, Meagre and Sole		Salmon	
		Larvae Materials	Juvenile - Grower Materials	Juvenile	Adult
Technological Additives	Preservatives	Sorbic acid, calcium propionate, orthophosphoric acid and sodium Propionate	Sorbic acid, calcium propionate, orthophosphoric acid and sodium Propionate	Sorbic acid, calcium propionate, orthophosphoric acid and sodium Propionate	Sorbic acid, calcium propionate, orthophosphoric acid and sodium Propionate
	Antioxidants	BHA, BHT, propyl gallate and citric acid	BHA, BHT, propyl gallate and citric acid	BHA, BHT, propyl gallate and citric acid	BHA, BHT, propyl gallate and citric acid
	Emulsifiers	lecithin, phospholipids	lecithin, phospholipids		
	Stabilizers				
	Thickeners				
	Gelling agents				
	Binders	fish gelatine	fish gelatine		
	Anticaking agents				
Sensory additives	Colourants			Astaxanthin	Astaxanthin
	Flavouring compounds				
Nutritional additives	Vitamins	A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, choline chloride	A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, choline chloride, inositol	A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, choline chloride	A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, choline chloride
	Minerals	phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc	phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc	phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc	phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc
	Amino acids	methionine	lysine, methionine and threonine	Methionine	lysine, methionine and threonine
	Digestibility enhancers				

Additive Category		Seabream, Seabass, Meagre and Sole		Salmon	
		Larvae Materials	Juvenile - Grower Materials	Juvenile	Adult
Zootechnical Additives	Gut flora stabilizers	Probiotics (*Pediococcus acidilactici*)	Probiotics (*Pediococcus acidilactici*)	Probiotics (*Pediococcus acidilactici*)	Probiotics (*Pediococcus acidilactici*)
	Others	herb extracts	herb extracts		

Additive Category		Turbot		Shrimp	
		Larvae Materials	Juvenile - Grower Materials	Juvenile	Adult
Technological Additives	Preservatives	sorbic acid, calcium propionate, orthophosphoric acid and sodium Propionate	sorbic acid, calcium propionate, orthophosphoric acid and sodium Propionate	sorbic acid, calcium propionate, orthophosphoric acid and sodium Propionate	
	Antioxidants	BHA, BHT, propyl gallate and citric acid	BHA, BHT, propyl gallate and citric acid	BHA, BHT, propyl gallate and citric acid	
	Emulsifiers	lecithin, phospholipids	lecithin, phospholipids	lecithin, phospholipids	
	Stabilizers				
	Thickeners				
	Gelling agents				
	Binders				
	Anticaking agents				
Sensory additives	Colourants				
	Flavouring compounds				
Nutritional additives	Vitamins	A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, choline chloride	A, B1, B2, B3, B5, B6, B7, B9, B12, C, D3, E, K3, choline chloride, inositol		

Additive Category		Turbot		Shrimp	
		Larvae Materials	Juvenile - Grower Materials	Juvenile	Adult
	Minerals	phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc	phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc		
	Amino acids	methionine	lysine, methionine and threonine	methionine	
Zootechnical Additives	Digestibility enhancers				
	Gut flora stabilizers	Probiotics (Pediococcus acidilactici)	Probiotics (Pediococcus acidilactici)		
	Others				

Additive Category		Common carp		Rainbow trout	
		Juvenile	Adult	Juvenile	Adult
Technological Additives	Preservatives				
	Antioxidants			BHT , BHA	BHT , BHA
	Emulsifiers				
	Stabilizers				
	Thickeners				
	Gelling agents				
	Binders				
	Anticaking agents				
Sensory additives	Colourants			Astaxanthin	Astaxanthin

Additive Category		Common carp		Rainbow trout	
		Juvenile	Adult	Juvenile	Adult
	Flavouring compounds				
Nutritional additives	Vitamins			A,D3	A,D3
	Minerals	phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc	phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc	phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc	phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc
	Amino acids				
Zootechnical Additives	Digestibility enhancers				
	Gut flora stabilizers	Prebiotic preparation Safmannan® (min. 20% mannan-oligosaccharides and min. 20% beta-glucans), Probiotics (Leuconostac sp., Lactobacillus sp.) ,Extracts and preparations from Saccharomyces cerevisiae, β-glucans, mannan oligosaccharides	Prebiotic preparation Safmannan® (min. 20% mannan-oligosaccharides and min. 20% beta-glucans), Probiotics (Leuconostac sp., Lactobacillus sp.) ,Extracts and preparations from Saccharomyces cerevisiae, β-glucans, mannan oligosaccharides	Extracts and preparations from Saccharomyces cerevisiae, β-glucans, mannan oligosaccharides, Bactocell® (Pediococcus acidilactici), Probiotics (Lactobacillus sp., Bifidobacterium sp.)	Extracts and preparations from Saccharomyces cerevisiae, β-glucans, mannan oligosaccharides, Bactocell® (Pediococcus acidilactici), Probiotics (Lactobacillus sp., Bifidobacterium sp.)
	Others	Nucleotides	Nucleotides		

Additive Category		Sturgeons	
		Juvenile	Adult
Technological Additives	Preservatives		
	Antioxidants	BHT , BHA	BHT , BHA
	Emulsifiers	Lecithin	Lecithin

Additive Category		Sturgeons	
		Juvenile	Adult
	Stabilizers		
	Thickeners		
	Gelling agents		
	Binders		
	Anticaking agents		
Sensory additives	Colourants		
	Flavouring compounds		
Nutritional additives	Vitamins	A,D3	A,D3
	Minerals	phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc	phosphorus, calcium, iron, iodine, copper, manganese, selenium and zinc
	Amino acids		
Zootechnical Additives	Digestibility enhancers		
	Gut flora stabilizers	Extracts and preparations from *Saccharomyces cerevisiae*, β-glucans, mannan oligosaccharides, Probiotics (Lactobacillus sp., *Bifidobacterium* sp.), Bactocell® (*Pediococcus acidilactici*)	Extracts and preparations from *Saccharomyces cerevisiae*, β-glucans, mannan oligosaccharides, Probiotics (Lactobacillus sp., *Bifidobacterium* sp.), Bactocell® (*Pediococcus acidilactici*)
	Others		

11. Annex 5 - Sustainability factors

11.1. Resource requirements for different materials

The resource requirements for 62 of the most commonly used aquafeed materials are provided below. Peer reviewed papers, in addition to, carboncloud ([202]), and Simapro 9.6 LCA software ([203]) utilizing life cycle inventory databases Agri Footprint 5 (An Paassen *et al*., 2019) and Ecoinvent 3 (Wernet *et al*, 2016) were searched to identify key sustainability factors for each material including:

- Water use (m3/t) – the total volume of fresh water consumed (appropriated, evaporated, or incorporated into the product) throughout its life cycle, measured in cubic meters per tonne of product.
- Land requirement (ha/t) – the total land area (in hectares) occupied or transformed over a specific period to produce one tonne of product. Accounting for agricultural, industrial, or forestry land use.
- Energy consumption electricity (kWh/t) - the total amount of electrical energy consumed from the power grid or on-site generation, measured in kilowatt-hours per tonne of product.
- Energy consumption electricity fossil fuel (kWh/t) - the total thermal energy extracted and consumed from fossil resources (such as coal, oil, and natural gas), converted and expressed in kilowatt-hours equivalent per tonne of product.
- Greenhouse gas emissions (t CO_2-eq/t) – the carbon footprint or climate change impact. Quantifies all greenhouse gas emissions released, converted into tonnes of Carbon Dioxide equivalents based on their Global Warming Potential, per tonne of product.
- Eutrophication marine (kg N eq/t) – the environmental impact of nutrient enrichment (mainly nitrogen) in marine ecosystems, which causes excessive algae growth and oxygen depletion, measured in kilograms of Nitrogen equivalents per tonne of product.
- Ecotoxicity freshwater (CTUe/t) - the toxic impact of chemical emissions on freshwater ecosystems. Measured in Comparative Toxic Units per tonne of product, which estimates the fraction of species potentially affected per unit mass of chemical emitted.
- Particulate matter (disease inc./t) - the human health impact resulting from the inhalation of fine particulate matter and its precursors. Measures

([202]) https://carboncloud.com/carboncloud-platform/

([203]) https://simapro.com/

the predicted increase in disease incidence (cases of respiratory illness or premature mortality) per tonne of product.

Economic allocation ([204]) was used when allocating impacts to products, (which avoids the over application of emissions to waste such as husks or straw).

([204]) When a given process produces several products, the environmental impacts generated in the process should be allocated to the products. The economic allocation is a method of partitioning the impacts among output products based on their relative economic value. Thus, more valuable products receive larger share of the impact. (i.e. In a milling process producing flour, husks or straw, the flour will receive relative more impact than husks or straw).

Table 169 - Materials impact on environmental sustainability factors using economic allocation

Material ([source])	Water use (m3/t)	land requirement (ha/t)	Energy consumption electricity (kWh/t)	Energy consumption fossil fuel (kWh/t)	Green-house gas emissions (tn CO2eq/t)	Eutrophication, marine (kg N eq/t)	Ecotoxicity, freshwater (CTUe/t)	Particulate matter (disease inc./t)
Algal oil ([205])	387.00			39,444.00	18.10	2.50		
Antioxidant [on example of BHT, E 321] ([206])					25.00			
Astaxanthin ([207])	157,813.00	15.78		2,268,403.00	412.00			
Barley ([208])	625.00	0.20		2,897.00	0.22			
Binders [example of modified Strach] ([209])			169.40	371.94	1.76			
Blood meal ([210])			611.11	2,584.88	2.38	7.52	71,253.45	0.00019
Calcium phosphate ([211])	5.09		414.18	12.42	0.77	0.20	0.33	3.45000
Camelina oil ([212])	7,567.00	2.24		7,811.50	0.50			
Choline chloride ([213])				25,000.00	15.00			
Coconut oil ([214])	34,775.01		111.58	53.31	2.84	4.12	7.56	0.00014

([205]) https://apps.carboncloud.com/climatehub/product-reports/id/4155810372693
([206]) https://apps.carboncloud.com/climatehub/product-reports/id/175193200163
([207]) Panis & Carreon. (2016) ; Rabbani *et al*. (2024)
([208]) Rodríguez *et al* (2024); Khan *et al* (2010)
([209]) https://apps.carboncloud.com/climatehub/product-reports/id/3301267887868
([210]) DDBB: Agrifootprint 5
([211]) Zhou *et al* (2021)
([212]) Zhang *et al* (2024)
([213]) Yao *et al* (2020) ; https://apps.carboncloud.com/climatehub/product-reports/id/1940938573297;
([214]) DDBB: Agrifootprint 5 - YIELD: 11,71 tn of coconut orchard/tn coconut oi) / ECON-ALLOC.: 91 % to coconut oil & 9 % to copra meal - Country PH

Material (source)	Water use (m3/t)	land requirement (ha/t)	Energy consumption electricity (kWh/t)	Energy consumption fossil fuel (kWh/t)	Green-house gas emissions (tn CO2eq/t)	Eutrophication, marine (kg N eq/t)	Ecotoxicity, freshwater (CTUe/t)	Particulate matter (disease inc./t)
Maize gluten ([215])	166.66		64.18	1,489.76	1.28	8.70	6.21	0.00008
Maize oil ([216])					2.51			
DDGS (distiller’s grains) ([217])	3,904.00	0.55	975.00		15.10			
DL-Methionine ([218])					3.10			
Faba bean dehulled ([219])	714.97		232.15	141.93	1.15	8.28	12.06	0.00011
Faba beans ([220])	493.42		232.15	141.93	0.59	8.28	8.18	0.00007
Feather meal ([221])			451.00	2,983.00	8.80			
Fish meal, cut-offs ([222])			39.81	1,533.00	1.36	1.77	1.77	0.00014
Fish meal, forage fish			39.81	1,533.00	0.94	2.37	2.37	0.00015
Fish oil, cut-offs			87.07	3,352.56	2.97	3.87	3.87	0.00030
Fish oil, forage fish			87.07	3,352.56	2.05	5.19	5.19	0.00033
Guar protein ([223])		0.70			1.87			

([215]) DDBB: Agrifootprint 5 - YIELD: 4,87 tn corn/tn corn gluten) - ECON-ALLOC.: 96 % to maize steeped, 86 % maize degermed & 8 % maize bran - Country: FR
([216]) https://apps.carboncloud.com/climatehub/product-reports/id/3222064829499
([217]) Hünerberg *et al* (2014)
([218]) Kim *et al* (2024) ; https://apps.carboncloud.com/climatehub/product-reports/id/1725680200693;
([219]) DDBB: Agrifootprint 5 - YIELD 1,61 tn beans/tn dehulled beans - ECON-ALLOC.: 90 % to beans dehulled vs. 10 % to bean hull & 98 % to broad beans vs. dry straw- Country DE
([220]) DDBB: Agrifootprint 5 - ECON-ALLOC.: 98 % to broad beans vs. dry straw - country: DE)
([221]) Campos *et al* (2019)
([222]) DDBB: Ecoinvent 3
([223]) Antonanzas *et al*. (2023)

Material (source)	Water use (m3/t)	land requirement (ha/t)	Energy consumption electricity (kWh/t)	Energy consumption fossil fuel (kWh/t)	Green-house gas emissions (tn CO2eq/t)	Eutrophication, marine (kg N eq/t)	Ecotoxicity, freshwater (CTUe/t)	Particulate matter (disease inc./t)
Hydrogenated vegetable fat ([224])					6.14			
Hydrolysed marine proteins ([225])	6.30		3,366		4.89			
Krill meal ([226])				1.92	3.78	11.10	11.10	0.00040
Lecithin ([227])					1.74			
Linseed oil ([228])	10,331.01	2.27		187.79	2.22	36.95	2,110,849.28	0.00030
L-Tryptophan ([229])					18.70			
Lupin ([230])		0.40		8,875.00	0.55			
Marine algae ([231])					8.48			
Monoammonium phosphate ([232])					4.86			
Oats ([233])	1,788.00	0.32	0.34		0.86	40.94	40.94	0.00012

([224]) https://apps.carboncloud.com/climatehub/product-reports/id/3605833544293 https://apps.carboncloud.com/climatehub/product-reports/id/3605865519690
([225]) https://apps.carboncloud.com/climatehub/product-reports/id/2895979730893
([226]) DDBB: Agrifootprint 5
([227]) https://apps.carboncloud.com/climatehub/product-reports/id/6756849041658
([228]) DDBB: Agrifootprint 5 - YIELD: 2,85 tn linseed/tn linseed oil - ECON-ALLOC.: 67% of linseed-to-linseed oil vs. 33% to linseed meal & 93 % to linseed vs. linseed straw - Country: RU
([229]) Overcash *et al* (2022)
([230]) https://apps.carboncloud.com/climatehub/product-reports/id/60497451124
([231]) https://apps.carboncloud.com/climatehub/product-reports/id/2895979730893
([232]) https://apps.carboncloud.com/climatehub/product-reports/id/147566457155
([233]) DDBB: Ecoinvent 3 (water from Mekonen and Hoekstra 2011)

Material (source)	Water use (m3/t)	land requirement (ha/t)	Energy consumption electricity (kWh/t)	Energy consumption fossil fuel (kWh/t)	Green-house gas emissions (tn CO2eq/t)	Eutrophication, marine (kg N eq/t)	Ecotoxicity, freshwater (CTUe/t)	Particulate matter (disease inc./t)
Pea flour ([234])	626.76	0.34	233.35	142.67	0.97	10.78	329,464.34	0.00010
Pea protein ([235])	1,093.05	0.60	13.45	1,339.50	2.11	23.28	630,682.55	0.00016
Phosphate ([236])					1.70			
Potato starch ([237])	333.57	0.08		219.44	0.91	11.47	468,509.47	0.00011
Poultry meal (values for blood meal assumed) ([238])			611.11	2,584.88	2.38	7.52	71,253.45	0.00019
Probiotics ([239])					5.00			
Rapeseed cake (expeller) / Rapeseed meal ([240])	528.31	0.13	41.30	224.88	0.66	8.55	93,864.35	0.00006
Rapeseed oil ([241])	1,519.42	0.38	46.63	253.06	2.32	33.41	1,600,690.83	0.00024
Rye bran ([242])					0.22			

([234]) DDBB: Agrifootprint 5 - YIELD: 1,21 tn pea dry/tn pea meal - ECON-ALLOC.: 98 % to peas vs. straw & 89 % to pea meal vs. pea hull - Country: FR
([235]) DDBB: Agrifootprint 5 - YIELD: 4,1 tn pea dry/tn pea protein concentrate - ECON-ALLOC.: 98 % to peas vs. straw & 53 % to pea protein concentrate vs. pea starch-concentrate - Country: FR
([236]) https://www.carbonchain.com/blog/understand-your-synthetic-fertilizer-emissions#:~:text=Around%202.6%20tonnes%20of%20carbon,activities%20of%20production%20and%20transportation.
([237]) DDBB: Agrifootprint 5 - YIELD: 4,2 tn potatoes/tn potato starch - ECON-ALLOC.: 86 % to potato starch vs. 11 % potato protein, 1 % potato juice & 2 % potato pulp - Country: DE
([238]) DDBB: Agrifootprint 5
([239]) Calculation for *Saccharomyces cerevisiae*; https://apps.carboncloud.com/climatehub/product-reports/id/468727344623
([240]) DDBB: Agrifootprint 5 - YIELD: 2,42 tn rapeseed/tn rapeseed meal - ECON-ALLOC.: 20 % to rapaseed meal vs 80 % oil - Country: DE&FR
([241]) DDBB: Agrifootprint 5 - YIELD: 1,74 tn rapeseed/tn rapeseed oil - - ECON-ALLOC.: 20 % to rapaseed meal vs 80 % oil - Country: DE&FR
([242]) https://apps.carboncloud.com/climatehub/product-reports/id/7985087991222

Material (source)	Water use (m3/t)	land requirement (ha/t)	Energy consumption electricity (kWh/t)	Energy consumption fossil fuel (kWh/t)	Green-house gas emissions (tn CO2eq/t)	Eutrophication, marine (kg N eq/t)	Ecotoxicity, freshwater (CTUe/t)	Particulate matter (disease inc./t)
Shrimp meal (equivalent of fish meal -cut offs assumed) ([243])			39.81	1,533.00	1.36	1.77	1.77	0.00014
single cell protein [an example of FeedKind raw material] ([244])	19.00	0.00			5.80			
Sodium propionate ([245])					3.79			
Soy (soya) ([246])	1,964.07	0.31	0.05	210.75	5.59	5.46	321,072.04	0.00004
Soy lecithin ([247])	3,078.19	0.48	33.80	145.23	9.78	10.25	527,702.48	0.00008
Soy protein concentrate ([248])	2,289.12	0.36	311.22	207.48	6.70	8.62	11,734.58	0.00084
Soybean meal ([249])	1,544.74	0.24	55.78	334.70	4.66	4.90	253,087.36	0.00004
Soybean oil ([250])	4,026.34	0.49	63.39	380.35	12.92	13.58	701,129.03	0.00011
squid meal (equivalent of fish meal -cut offs assumed) ([251])			39.81	1,533.00	0.94	2.37	2.37	0.00015

([243]) DDBB: Ecoinvent 3
([244])Carbon Trust. (2016). Assessment of environmental impact of FeedKind protein [Raport]. Carbon Trust.
([245]) https://apps.carboncloud.com/climatehub/product-reports/id/7989308743626
([246]) DDBB: Agrifootprint 5 - ECON-ALLOC.: 90 % to soybeans vs. 10 straw - Country BR
([247]) DDBB: Agrifootprint 5 - YIELD: 250 tn soybean/tn soy lecithin - ECON-ALLOC.: 1,5 % from soy oil to to lecithin & 41 % from soy crop to soy oil & 90 % to soybeans vs. straw - Country: BR
([248]) DDBB: Agrifootprint 5 - YIELD: 1,85 tn soybean/tn soy protein concentrate - ECON-ALLOC.: 63 % to soy protein concentrate vs. hulls, molasses and oil & 90 % to soybeans vs. straw - Country: BR
([249]) DDBB: Agrifootprint 5 - YIELD: 1,43 tn soybean/tn soy meal - ECON-ALLOC.: 55 % to soymeal vs. hulls and oil & 90 % to soybeans vs. straw - Country: BR
([250]) DDBB: Agrifootprint 5 - YIELD: 5 tn soybean/tn soybean oil - ECON-ALLOC.: 41 % to soy oil vs. meal and hulls & 90 % to soybeans vs. straw - Country: BR
([251]) DDBB: Ecoinvent 3

Material (source)	Water use (m3/t)	land requirement (ha/t)	Energy consumption electricity (kWh/t)	Energy consumption fossil fuel (kWh/t)	Green-house gas emissions (tn CO2eq/t)	Eutrophication, marine (kg N eq/t)	Ecotoxicity, freshwater (CTUe/t)	Particulate matter (disease inc./t)
Sunflower meal ([252])	1,992.51	0.31	7.30	135.24	0.56	6.90	143,550.50	0.00040
Sunflower ([253])	3,495.64	0.55	0.52	536.59	0.56	6.90	143,550.50	0.00040
Triticale ([254])	848.26	0.23	0.03	267.58	0.39	7.65	66,892.95	0.00005
Vitamin & mineral premix ([255])					15.00			
Vitamin C ([256])					25.00			
Vitamin E50 ([257])					31.03			
Wheat flour ([258])	1,242.39	0.11	81.21	48.72	0.71	12.80	62,900.31	0.00009
Wheat gluten ([259])	580.28	0.05	358.08	1,074.23	0.72	7.31	35,349.24	0.00005
Wheat middlings ([260])					0.25			
Wheat ([261])	1,079.58	0.09		407.58	0.47	11.77	292,344.41	0.00009
Whey ([262])					7.96			

([252]) DDBB: Agrifootprint 5 - YIELD: 2,85 tn sunflower/tn sunflower meal - ECON-ALLOC.: 20 % to sunflower meal vs. oil and hull - Country: RU
([253]) DDBB: Agrifootprint 5 Country: RU
([254]) DDBB: Agrifootprint 5 - ECON-ALLOC.: 85 % to grain vs. straw - Country: PL
([255]) https://apps.carboncloud.com/climatehub/product-reports/id/186640392289
([256]) https://apps.carboncloud.com/climatehub/product-reports/id/187855457375
([257]) https://apps.carboncloud.com/climatehub/product-reports/id/2912766814318
([258]) DDBB: Agrifootprint 5 - YIELD: 1,37 tn wheat grain/tn wheat flour - ECON-ALLOC.: 84% from grain to flour vs. germ, middlings and bran & 84 % to grain vs. straw - Country: CN
([259]) DDBB: Agrifootprint 5 - YIELD: 10,75 tn wheat grain/tn wheat gluten feed - ECON-ALLOC.: 5% from grain to gluten feed vs. starch and bran & 84 % to grain vs. straw - Country: CN
([260]) Vellinga *et al* (2009)
([261]) DDBB: Agrifootprint 5 - ECON-ALLOC. 84 % to grain vs. straw - Country: CN
([262]) https://apps.carboncloud.com/climatehub/product-reports/id/153737708776

Material (source)	Water use (m3/t)	land requirement (ha/t)	Energy consumption electricity (kWh/t)	Energy consumption fossil fuel (kWh/t)	Green-house gas emissions (tn CO2eq/t)	Eutrophication, marine (kg N eq/t)	Ecotoxicity, freshwater (CTUe/t)	Particulate matter (disease inc./t)
Yeast autolysate ([263])	1175	1.3	2550		4.24			
Mean	7,961.5	1.06	250.1	63,393.4	12.0	10.1	247,999.5	0.1080
Median	1,175	0.34	72.7	472.1	2.4	7.6	64,896.6	0.0001

([263]) https://apps.carboncloud.com/climatehub/product-reports/id/40832581969

11.2. Case study on socio-economic aspects of soy

Soy is a major material in aquafeeds worldwide and is the main replacement source of protein when reducing fishmeal inclusion (FAO, 2025b). Global production of soy in 2023 was around 371 Mt, of which more than 78% comes from just three countries, Brazil (41%), the USA (30%) and Argentina (7%) (FAO, 2024a). These three countries report a total of 2,976,304 people involved in the soy production chain (including farming, seed delivery, processing, transport, feed, and biofuel production). A total of 703,000 people were recorded as being involved in soybean production / farming with 479,000 in Brazil ([264]), 164,065 in the USA ([265]), and 60,000 in Argentina ([266]). Most of the production and therefore related employment is for soy destined for sectors other than aquaculture. Around 20% of global soy production is destined for the human food sector, 4% is used for industries such as biofuels and lubricants, the remaining 76% is used for animal feed (mainly poultry and pigs) with aquaculture using up 6% of global soy production between 2017-2019 ([267]). Assuming a proportional split between these countries this level of consumption by the aquaculture industry would result in 39,372 jobs in Argentina, the USA, and Brazil (78% of global production) in soy production and a total of people 166,673 in the value chain including production. Scaled up to 100% of soybean production this would equate to just under 50,500 jobs in production and just over 213,680 in the value chain.

This basic calculation suggests that from one material alone the employment of over a hundred thousand people is affected. Soy represents only a fraction of the total material use in aquafeed and while it is a major material in feeds for species like salmon, other species such as carp, shrimp, and tilapia see the inclusion of large percentages of crops like wheat, rice, and to a lesser extent maize and cassava (van Riel et al., 2023). Including the effect of these materials and that of marine materials, emerging materials, and vitamins and minerals the wide-reaching impact of the aquafeed industry in employment worldwide is apparent.

Soy production is a prime example of an aquafeed material with broader social sustainability effects (Dreoni et al., 2022). However, these benefits arise alongside trade-offs that are less well documented and more challenging to measure. For instance, across various industries of soy production, documented negative impacts include occupational health risks and contamination of drinking water sources caused by agrochemical use (Lima

([264]) https://www.cepea.org.br/en/opinion/the-labor-market-in-the-soybean-and-biodiesel-production-chain-in-brazil.aspx
([265]) https://www.nopa.org/wp-content/uploads/2023/08/0LMC_SoyEconStudy_Aug2023.pdf
([266]) https://thecollaborativesoyinitiative.info/storage/files/ciara-argentine-soy-sector-nov22-1.pdf
([267]) Hannah Ritchie (2021) - “Drivers of Deforestation” Published online at OurWorldinData.org. Retrieved from: 'https://ourworldindata.org/drivers-of-deforestation' [Online Resource]

et al., 2011). Soy feed production can also undermine cultural and social well-being, diminishing traditional agricultural practices and rural lifestyles, and reducing the sense of freedom and security associated with land ownership and access to development opportunities (Auer et al., 2017). Local communities may experience pressure to sell land or conform to agrobusiness priorities, resulting in displacement or migration (Dreoni et al., 2022; Lima et al., 2011). Thus, while soy production can generate measurable positive benefits through employment and income, these are often alongside trade-offs with other, less quantifiable yet significant, social sustainability impacts.

11.3. Review of certification schemes and their impact on sustainability in the aquafeed sector

11.3.1. Environmental sustainability

With regards to sustainability, just over half of schemes (55%) had requirements on sustainable sourcing. The specificity of this requirement differed between standards with some simply requiring a supplier approval process whilst others such as the ASC feed standard ([268]) and GLOBALG.A.P ([269]) have required inclusion percentages for certified marine and agricultural materials in addition to supplier due diligence. All standards with specific sourcing requirements recognised difficulties in achieving consistent and reliable supply of certified materials and as such have allowances for a percentage of materials to be sourced from non-certified sources, often with the stated requirement to reduce this percentage over time. Some standards go further and apply different requirements depending on the species being produced, with some sectors such as salmon, thought to be able to tolerate more stringent sustainability criteria.

The Naturland standard ([270]) was the only standard which required that each supplier of materials be approved by the certification body before they can be used and this fits within the more niche and restrictive requirements of the standard being primarily focused on organic production. With the exception of Naturland most certification schemes only require that the producer have supplier approval processes in place and conduct due diligence on the materials being brought in, this may include the use of preferred buyer lists but the actual requirements of supplier approval are rarely prescriptive and for the majority of materials are focused on safety rather than sustainability. GMP+ ([271]) requires that materials used are present on an approved product list, this list is

([268]) https://asc-aqua.org/producers/asc-standards/feed-standard/
([269]) https://www.globalgap.org/what-we-offer/solutions/compound-feed-manufacturing
([270]) https://www.naturland.de/en/naturland/what-we-stand-for/quality/naturland-quality-standards/4072-aquaculture.html
([271]) https://www.gmpplus.org/feed-certification-scheme/scheme-documents/fsa-requirements/

extensive and describes the type of permissible materials, but it does not cover geographical origin, species origin, or other factors linked to sustainability. This requirement is under the scheme Feed Safety Assurance requirements rather than the Feed Responsibility Assurance requirements.

Only four groups of materials are specifically mentioned as having mandatory sustainability requirements: marine proteins, marine oils, soy, and palm oil. These products are mentioned in less than half of the assessed certification schemes, 41% of schemes mention requirements for the sustainable procurement of marine materials, in general these schemes are those that focus on aquafeed production or seafood such as those under ASC, MSC, MarinTrust, and B.A.P. Of the more general certification schemes only Naturland and GLOBALG.A.P have mandatory requirements for the sustainable sourcing of marine materials. Of the schemes assessed only 18% and 27% had prescriptive measures for the sustainable sourcing of palm oil and soy respectively. One caveat to this figure is that many of the schemes assessed focus on the particular elements of the aquafeed supply chain and therefore can not be expected to encompass all relevant materials or processes.

The focus on the sustainable sourcing on this small group of materials is due to the increased level of concern that these materials are affected by unsustainable fishing practices, deforestation, and biodiversity losses. Whilst other materials may vary in how sustainably they can be sourced, issues may be more case driven than systematic, or they are included in much smaller amounts and therefore have not warranted specific attention so far e.g. Astaxanthin.

Around half of assessed certification schemes had requirements on environmental sustainability outside of sourcing requirements. At its most basic this may be a requirement that a producer complies with all relevant local environmental legislation. More detailed standards may require the monitoring of water use, waste handling, effluent management, energy use, and GHG emissions of major feed materials (down to those with ≥1% inclusion), and require plans to be in place for the improvement of these metrics over time. Generally other environmental sustainability factors are not considered with the exception of deforestation (specifically soy and palm oil) and unsustainable fishing practices. Factors such as water use and energy consumption are not considered outside of the feed manufacturing stage and other common environmental sustainability metrics such as eutrophication (outside of effluent reduction), ecotoxicology, human toxicity, ozone depletion, and resource use are not considered within the scope of the certification schemes.

Certification schemes are seen by many to enhance the environmental sustainability of aquaculture, especially in nations with developing industries (Becke et al., 2025, Garcia et al., 2025). It stands to reason that well implemented certification schemes with specific environmental sustainability requirements and audit, and due diligence processes will have a net positive

effect on the variables covered but to date there has been little reach into quantifiable net positive environmental benefits of aquafeed certification schemes. Requirements to source all or the majority of marine materials from certified sources is likely to decrease the industry’s reliance on unsustainable sources of wild fish, a practice that has challenged the environmental sustainability of the industry (Ghamkhar & Hicks, 2020). This also applies when feed certification schemes require that other feed materials are sourced from certified suppliers such as palm oil or soy.

The benefits of using certified sources of materials only apply if the certified materials are truly sustainable. There is criticism from environmental groups about the veracity of sustainability claims from major marine ([272]), soy, and palm material certification schemes ([273]), with claims ranging from international greenwashing to inadequate measures to stop abuse and ensure true sustainability. More specifically of certain certified fisheries have been subject to criticism, these include the Russian Barents Red King Crab fishery (Kourantidou & Kaiser, 2019) and the Canadian snow crab fishery ([274]) due to the intentional introduction of invasive species and interactions with wild cetacean populations respectively. Whilst neither fishery produces materials for aquafeeds the certification of such fisheries and the general criticisms levelled against these schemes can reduce public trust in the certification process and in the environmental benefits of certification. Fishmeal and oil used in aquafeeds can originate from certified fisheries in the form of trimmings and by-products, but certification is not limited to fisheries for human consumption, and a number of reduction fisheries are certified, these fisheries operate primarily to supply the fishmeal and fish oil market ([275],[276]). Whilst being a reduction fishery does not mean the fishery is unsustainable the transformation of wild fish into fishmeal and oil for aquaculture is a major criticism against the aquaculture industry’s sustainability (Ghamkhar & Hicks, 2020).

11.3.2. Social sustainability

Certification schemes are voluntary frameworks that establish a set of defined criteria for responsible production, sourcing, and supply chain management, and are increasingly recognised as governance tools (Arnold, 2022). These

([272]) BLOOM Association. (2020). *The sham of the MSC label* (pp. 1–10). BLOOM Association. Retrieved from https://www.bloomassociation.org/wp-content/uploads/2020/05/sham-msc-label.pdf

([273]) Greenpeace International. (2021). *Destruction: certified*. Greenpeace International. Retrieved from https://www.greenpeace.org/static/planet4-international-stateless/2021/04/b1e486be-greenpeace-international-report-destruction-certified_finaloptimised.pdf

([274]) https://www.theguardian.com/environment/2021/jul/26/blue-ticked-off-the-controversy-over-the-msc-fish-ecolabel

([275]) https://fisheries.msc.org/en/fisheries/dfpo-dppo-and-spfpo-north-sea-skagerrak-and-kattegat-sandeel-sprat-and-norway-pout/

([276]) https://www.marin-trust.com/impacts/case-studies/panama-small-pelagics-fishery

certifications are often driven by market incentives, and although were originally established to address environmental concerns, they are increasingly integrating social dimensions of sustainability. Social factors include fair labour practices, living wages, human rights, and community wellbeing (Saha, 2024). Social criteria are becoming increasingly focal components in such standards, evolving to align with internationally recognised benchmarks, such as the International Labour Organisation (ILO) core conventions[277]. These include guidance on labour rights, non-discrimination, freedom of association, and minimum standards of social protection, amongst other factors (ILO, 1998).

Unlike more general supply chain standards, such as Fair Trade and Sedex, certification schemes in aquafeed supply chains are typically material-specific, targeting high-risk inputs such as soy and fishmeal. The ability of these schemes to promote socioeconomic sustainability, and their effectiveness in doing so, depends on their robustness, the rigour of audit processes, and the extent to which they are adopted and enforced throughout the supply chain. This is particularly challenging to achieve in aquafeed production, as the industry sits at the intersection of various global commodity chains with distinct socioeconomic challenges, from land rights in soy-producing regions, to food and nutrition security in West African FMFO producer countries, as described in Section 4.7.4.

Certification schemes, therefore, do not only influence the practices of producers and traders, but also the livelihoods of communities in the sourcing regions. Growing research on certification schemes has begun to examine their governance effectiveness, producer market access, value chain dynamics, and social performance (Saha, 2022), often showing an imbalanced treatment of the latter. A comparative assessment of six international aquaculture standards found that while workforce health, safety, and wellbeing are relatively well-covered, principles relating to indigenous peoples, local communities, and smallholders are less focal (Saha, 2024). For example, displacement and food insecurity are frequently overlooked, even though they are key socioeconomic concerns in sourcing regions. Studies have also shown that criteria such as fair wages, equitable distribution of benefits, and community wellbeing are either narrowly defined or entirely missed in major standards (Saha, 2024). Of the 22 aquafeed standards reviewed for this study, only 41% made specific mention to measures that producers must implement to improve the social sustainability of operations. The topics covered under social sustainability requirements were consistent between these certification schemes, relating to labour rules and regulations, worker rights, worker wages, child and forced labour, right to collective bargaining, and engagement with local communities. Apart from requirements for sourcing certain materials from certified sources, which themselves may have certain social sustainability requirements, there was no consideration of social sustainability in the wider value chain. Being market driven initiatives, it is perhaps not surprising that social sustainability is a lesser

([277]) https://normlex.ilo.org/dyn/nrmlx_en/f?p=NORMLEXPUB:12000:0::NO:::

focus of certification schemes given both feed manufacturers and fish farmers place a significantly higher importance on environmental than social sustainability factors (Cantillo et al., 2025).

To address the issue of limited social inclusion in sustainability-related certification schemes, a useful framework has been developed by the Canadian Fisheries Research Network (CFRN), providing a comprehensive tool to evaluate sustainability in fisheries (Stephenson et al. 2018a). The CFRN explicitly recognises the need to integrate both social and environmental objectives into management and evaluation, providing a structure that goes beyond environmental indicators. This model draws upon international obligations and best practices across Europe, Australia, and the United States, and can be applied in multiple contexts. One relevant application is its use as a benchmarking tool to evaluate the scope of environmental, economic, social, and governance principles within sustainability standards. By defining what a comprehensive set of principles should include, the framework helps to identify where existing standards are robust and where they fall short, making it a broadly relevant model for integrated sustainability assessments.

The CFRN identifies key social domains and performance indicators that are directly applicable to aquafeed certification (Stephenson *et al,* 2018b):

- Sustainable communities: Respecting and preserving indigenous and local knowledge, while ensuring resource use supports human well-being alongside ecosystem consideration (Convention on Biological Diversity, 2020; FAO, 2008). Performance indicators include social capital, informed citizenry, vital civic culture, individual and collective well-being, and self-determination.
- Ethical fisheries: Equity and the protection of artisanal and small-scale fishers’ rights, encompassing welfare, justice, fair access and the right to food (Convention on Biological Diversity, 2020; FAO, 2000, 2005).Performance indicators include adherence to standards of code of conduct, and individual and collective well-being.
- Health and well-being: safe, healthy and fair working and living conditions, while ensuring food and nutrition quality and security, and a wider community well-being (Convention on Biological Diversity, 2020; FAO, 2008). Performance indicators include social factors, proportion of population below the poverty line, availability of affordable services, seafood caught by local population, proportion of seafood consumed by local populations, and occupational safety.

The CFRN framework can be used a tool to evaluate the role of certification schemes in promoting social sustainability, clarifying socioeconomic sustainability impacts. However, evidence of such impacts remains limited. For instance, within soy certification schemes there is little evidence that certification consistently mitigates negative social impacts (Dreoni *et al*, 2022).

Moreover, studies specifically on the social benefits of aquafeed certification schemes are scarce. Many aquafeed scheme requirements are similar to those used in wider aquaculture certifications, including fair wages, prohibitions of child and forced labour, community interaction, and health and safety.

Furthermore, while schemes such as ASC and BAP incorporate workplace safety and non-discrimination clauses, they often overlook CFRN indicators of community issues such as consideration of indigenous people, ethical practices, issues of marginalisation, displacement of farmers and well-being of smallholders (Saha, 2024). In contrast, aquaculture production certification schemes are more established, and there is emerging evidence of their socioeconomic benefits. One recent study found that certification improved working conditions, health and safety, community consultation, and worker nutrition, with these benefits confirmed at the local community-level (MEP, 2023). Given the commonality in requirements between aquafeed and aquaculture certification schemes, when properly implemented, feed certification schemes could deliver similar social benefits.

11.3.3. Economic sustainability and Security of supply

With regards to economic sustainability, certification schemes can provide a price premium for labelled products. Eco-labelled fish is thought to have a price premium with consumers stating a willingness to pay more for eco-labelled aquaculture products (Hammarlund et al., 2025). On average this price premium is thought to be around 10-20% but this is not always the case and there is evidence that the premium does not always pass to the fish producer. This and the costs of certification can act as a disincentive ([278]). The lack of a price premium paid by consumers is further evidenced by the finding that the majority of certified Norwegian salmon sold at retail is sold without eco-labelling, with many producers and retailers using certification only at business to business level (Gulbrandsen et al., 2022). Even where evidence of price premiums is inconclusive other benefits like improved market access and improved production practices can improve the economic sustainability of certified operations with consumers in Europe more likely to prefer eco-labelled over non-labelled aquaculture products.

Certification is increasingly being seen as a requirement to enter certain markets with certification being required by many leading retailers (Gulbrandsen et al., 2022). Demand is from both retailer and feed buyer, of the major aquaculture companies in Europe (Mowi, SalMar, Leroy, Bakkafrost, Cermaq, Grieg, Cooke aquaculture) which represent almost 20% of the total EU market share ([279]), all require certification of either feeds or raw materials into feeds. Uncertified producers will have significantly reduced market share based on

([278]) Seafood certification and developing countries: focus on Asia
([279]) IbisWorld, Aquaculture in Europe, 2024.

these requirements. Certification provides economic benefits not only through market access but also though predictable, high-volume contract that might otherwise not be available if not certified (Amundsen & Osmundsen, 2020).

As mentioned above, all schemes contain requirements regarding traceability and a number also require that the manufacturer provide some degree of economic sustainability through the provision of fair wages, with a minimum wage being all the is typically required. Half of the standards make specific mention to food fraud, and prevention and mitigation measures are often similar to those covered by traceability and transparency measures but as mentioned earlier these measures are generally focused on issues relating to quality and safety rather than the intentional altering, misrepresenting, mislabelling, substituting, tampering of food/feed products for financial (food fraud) or contamination of food products for ideological purposes (food terrorism). The certification schemes specifically targeted at seafood (MarinTrust, MSC, ASC etc.) pay food fraud a higher degree of attention compared to other certification schemes and given the prevalence of food fraud in the seafood industry (Fox et al., 2018) this is not surprising. Measures include DNA tests on products in the supply chain to tackle mislabelling. Depending on the certification scheme they may employ different methods to certify the origin of products, with some requiring the physical separation of materials along the supply chain to distinguish between materials of certified and non-certified origin. Other certification schemes employ mass balance; this process uses a credit system and ensures that the volume of product produced on certified farms is equivalent to the volume that is sold to producers but during this process products from one farm may be mixed with another. The use of credits has been subject to criticism as it does not guarantee that the specific product in the hands of consumers has been produced in a sustainable manner ([280]). To avoid issues of double counting certification schemes like CRS will not allow farms to be certified under another scheme, this ensures that the total amount of certified soy produced is accurate.

Whilst protecting the security of supply of materials is not a primary aim of the majority of the assessed certification schemes, those that require inputs from certified, and therefore assumingly sustainable, sources will indirectly help to protect against supply issues caused by unsustainable farming or fishing practices. Overfishing especially when combined with events such as El Niño can put vulnerable stocks of fish at risk (Ballón et al., 2008; Castrejón et al., 2024) and as seen earlier can result in large price fluctuations which can threaten the economic sustainability of the industry. The Peruvian fishmeal and fish oil industry has suffered significant fluctuations in production over the years with a combination of overfishing and El Niño resulting in cancelled anchovy

([280]) Greenpeace International. (2021). *Destruction: certified*. Greenpeace International. Retrieved from https://www.greenpeace.org/static/planet4-international-stateless/2021/04/b1e486be-greenpeace-international-report-destruction-certified_finaloptimised.pdf

fishing seasons and decreases in production ([281]). Since 2009, Peru’s share of the European fishmeal and fish oil supply has shrunk from 64% and 47% respectively to 18% and 8%. The reason is multi-faceted and is also linked to increased demand for Peruvian fish products from China ([282]) but also the fact that the Peruvian anchovy fishery is uncertified. This means that for producers looking to gain feed certification this fishery is unsuitable for the majority of their fishmeal and oil inputs.

Through improvements to environmental sustainability certification schemes can also indirectly improve the economic sustainability of the sector. Environmental risks are a key consideration for investors and organisations such as the Farm Animal Investment Risk & Return (FAIRR) initiative flag a range of environmental issues including fish feed supply as risks to profits (Stuart, 2022). FAIRR is the only investor network looking at risks and opportunities in global food systems and represents more than USD12tn in assets under management.

11.3.4. Gaps

An important component of these schemes is that they are voluntary and therefore their adoption is market driven. As a result of the market driven nature of certification schemes there is a dichotomy between the level of certification in regions like Europe and regions like Asia. In places like Europe certification of aquaculture products is a common requirement among retailers and the region produces 45% of global certified seafood from only 15% of total seafood production, compare this to Asia, a region that produces around 70% of the world’s seafood but only 11% of certified production (Tsantiris *et al* 2018). That is not to say that consumers in Asia have less interest in sustainable seafood but that the prevalence of smaller scale fishers and producers, differences in supply chain such as a lack of middlemen, and the costs involved in gaining certification reduce the economic impetus to gain certification with the exception of larger producers supplying foreign markets where certification is expected. This difference in the uptake of certification schemes means that the socioeconomic benefits of the schemes are not fully realised in major production areas. The rate of certification is even lower when only aquaculture is considered with less than 5% of global production certified as of 2021, the fact that most farmed fish is consumed locally in areas where certification is of limited market value, compared to the wider global market where certification is more of an exception is seen as a reason behind the lack of impetus for certification (Naylor et al., 2021).

([281]) https://www.fao.org/in-action/globefish/news-events/news/news-detail/Fishmeal-and-fish-oil---July-2015/en

([282]) https://www.fao.org/in-action/globefish/news-events/news/news-detail/FIshmeal---November-2009/en

Even if local fish production is not generally certified in Asia, the farming of certified fish in other regions can still have a positive impact on communities due to requirements in sourcing. Raw materials such as soy, palm oil, and fish oil and meal are often sourced outside of Europe so required due diligence that feed companies in Europe must undertake can improve socioeconomic conditions around the world. Feed certification is expanding however and of ASCs 36 certified feed mills, 13 are in Latin America and 9 are in Asia ([283]).

Social sustainability is the least common requirement in the above reviewed certification schemes. Those standards that do have specific social sustainability requirements are generally limited to the fair treatment of staff, their families, and occasionally the immediate local community or indigenous populations (usually limited to disturbance of the community by different forms of pollution or land use). For certification schemes covering the production of aquafeeds social sustainability within the value chain, with the exception of material sourcing requirements, is not considered within scope. Environmental sustainability is covered to some extent by around half of the certification schemes; there are differences in the extent to which each scheme dictates specificities of the production process with some requiring certain percentages of materials from certified sources whilst others simply require alignment with local regulations.

As can be seen in Annex 1, there are large differences between the coverage of certification schemes. What has not been assessed are the various requirements of the schemes with regards to evidence and auditing. Each certification scheme has its own internal requirements, and this allows producers to pick schemes that fit within their organisational structure and provide the benefits they desire. This is a positive and market driven dynamic, but it also allows producers to pick and choose a scheme which will allow them to become certified with the minimal amount of effort and potentially the minimum improvement to the sustainability of operations. The ability to pick and choose schemes of least effort is linked to the preferences of buyers and their understanding of the true sustainability credentials of each scheme, if buyers (the market) steer producers to more sustainable schemes those that do not fulfil the requirements of the market will be driven out. Whilst certification schemes can be useful in promoting sustainable practices, they alone will not result in systematic change as long as there is a market for less sustainable products, achieving widespread change requires improvements in sustainability legislative and regulatory measures.

([283]) https://asc-aqua.org/find-feed-mill/

12. Annex 6 – Stakeholder survey results

Figure 103 – Stakeholder survey responses to the question: Rate the possible negative impacts of the use of fishmeal and fish oil materials in aquafeeds [Exploitation of wild fish stocks] (n=75)

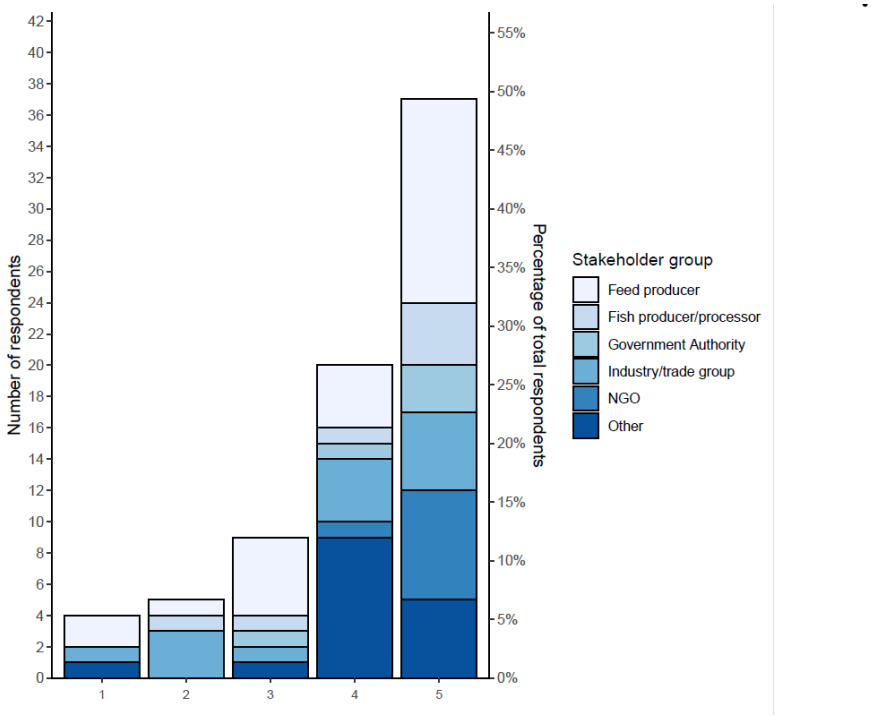


Figure 104 – Stakeholder responses to the question: Rate the possible negative impacts of the use of fishmeal and fish oil materials in aquafeeds [Impacts on marine biodiversity and ecosystem balance] (n=74)

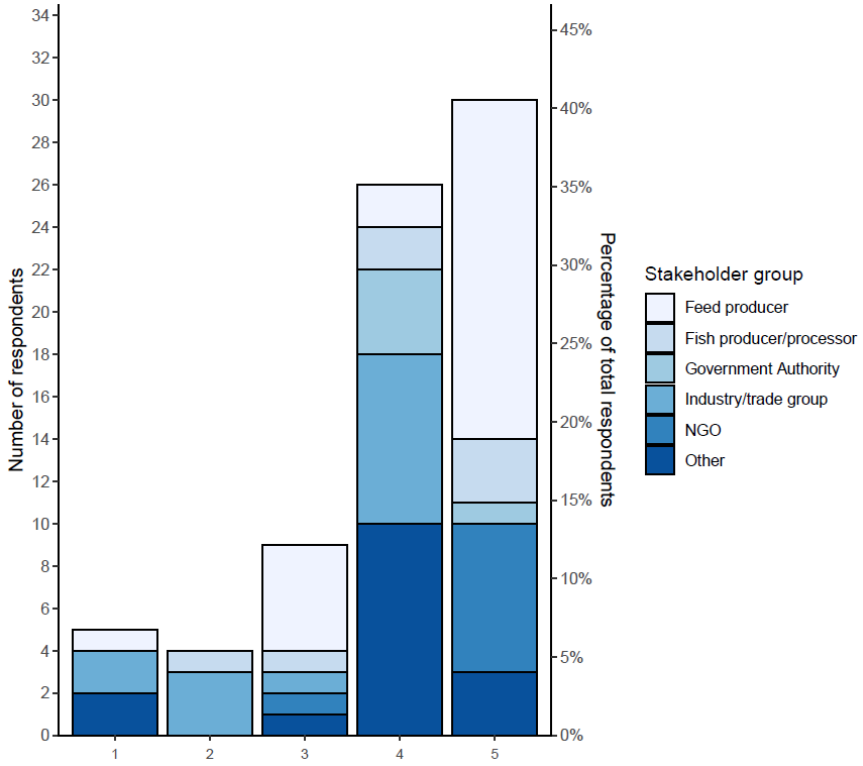


Figure 105 – Stakeholder responses to the question: Rate the possible negative effects of increasing the use of terrestrially produced aquafeed materials [Depletion of natural resources (e.g. deforestation for soy production, increased usage of freshwater for crop irrigation)] (n=74)

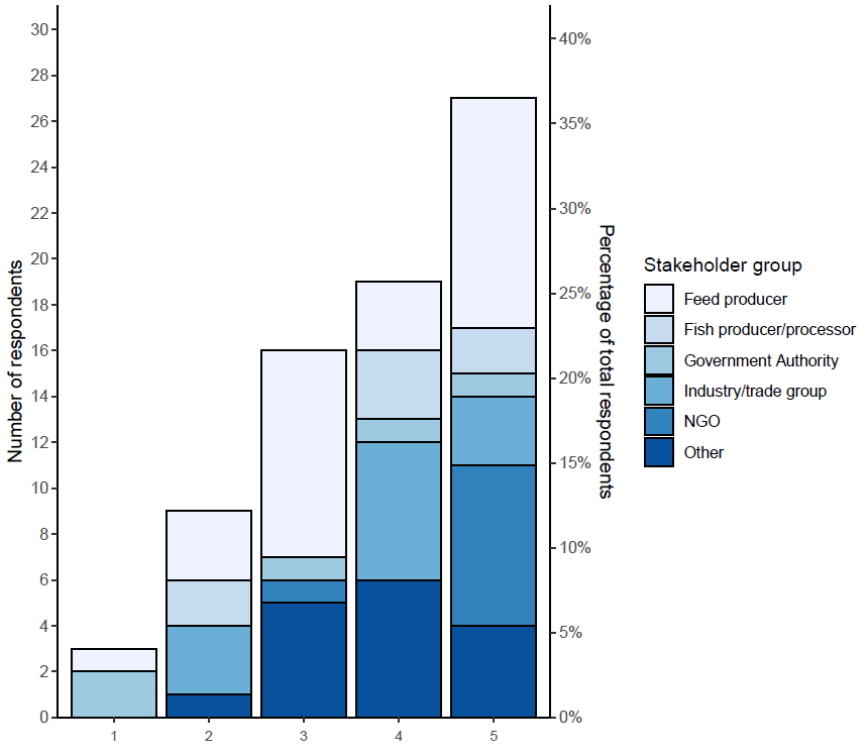


Figure 106 – Stakeholder responses to the question: Rate the possible negative effects of increasing the use of terrestrially produced aquafeed materials [Increased input demand on agriculture (e.g. pesticides, fossil fuels)] (n=72)

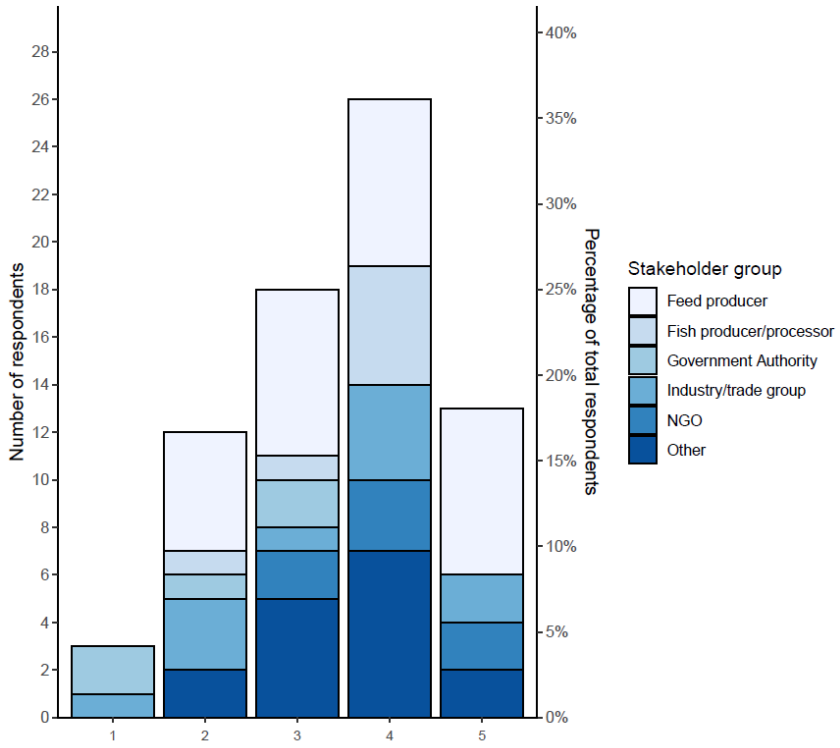


Figure 107 – Stakeholder responses to the question: Rate the following materials in terms of the security and reliability of its supply chain [Fishmeal] (n=68)

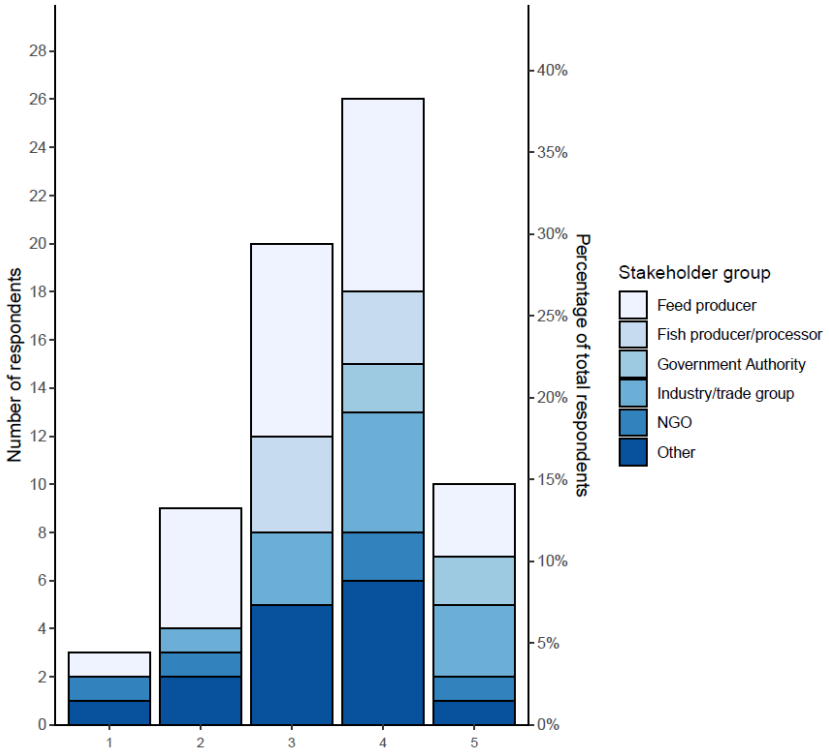


Figure 108 – Stakeholder responses to the question: Rate the following materials in terms of the security and reliability of its supply chain [Fish oil] (n=68)

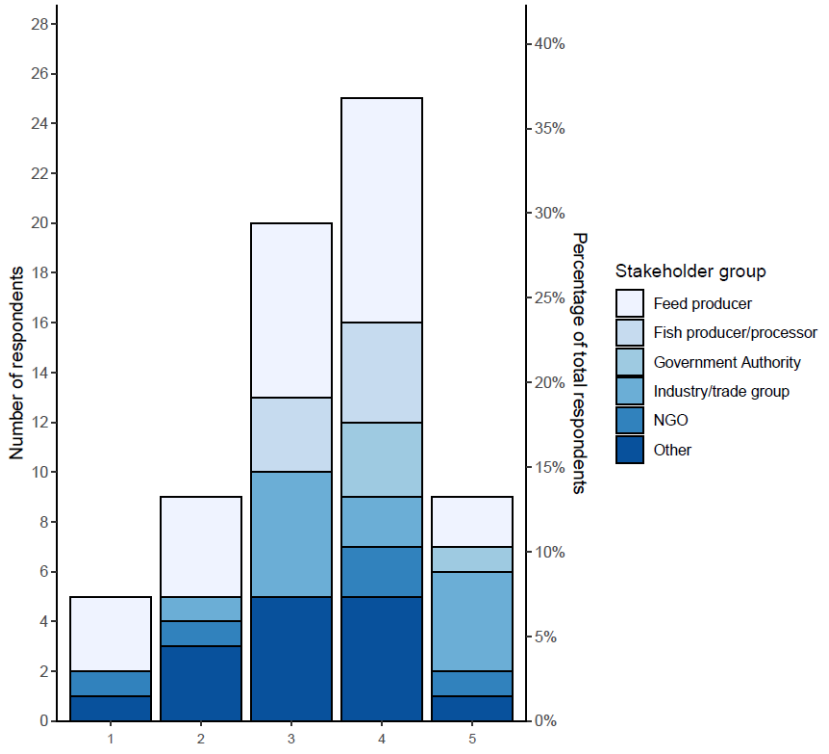


Figure 109 – Stakeholder responses to the question: Rate the following materials in terms of the security and reliability of its supply chain [Soybean meal] (n=63)

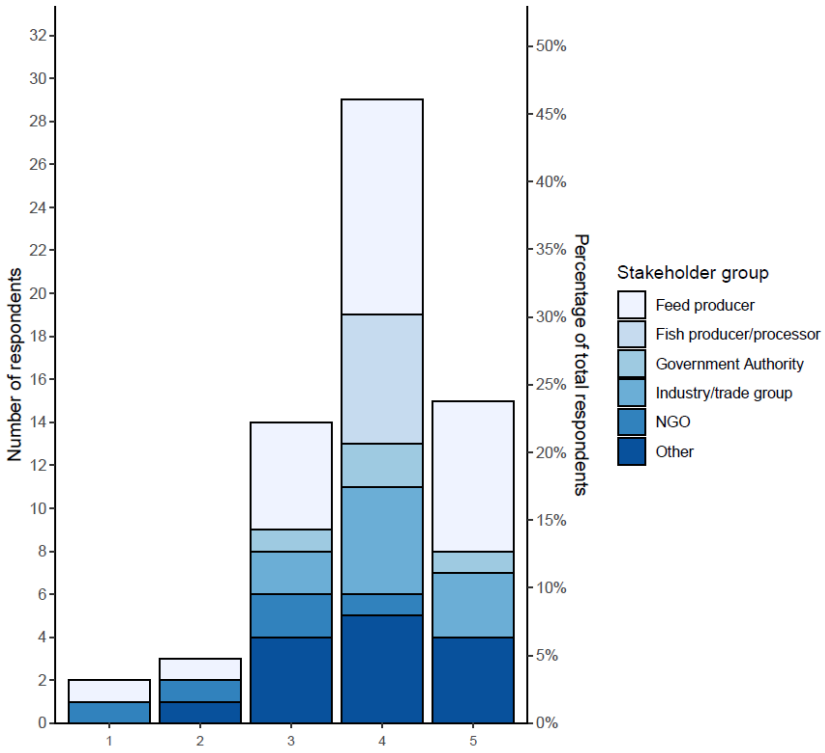


Figure 110 – Stakeholder responses to the question: Rate the following materials in terms of the security and reliability of its supply chain [Maize meal] (n = 62)

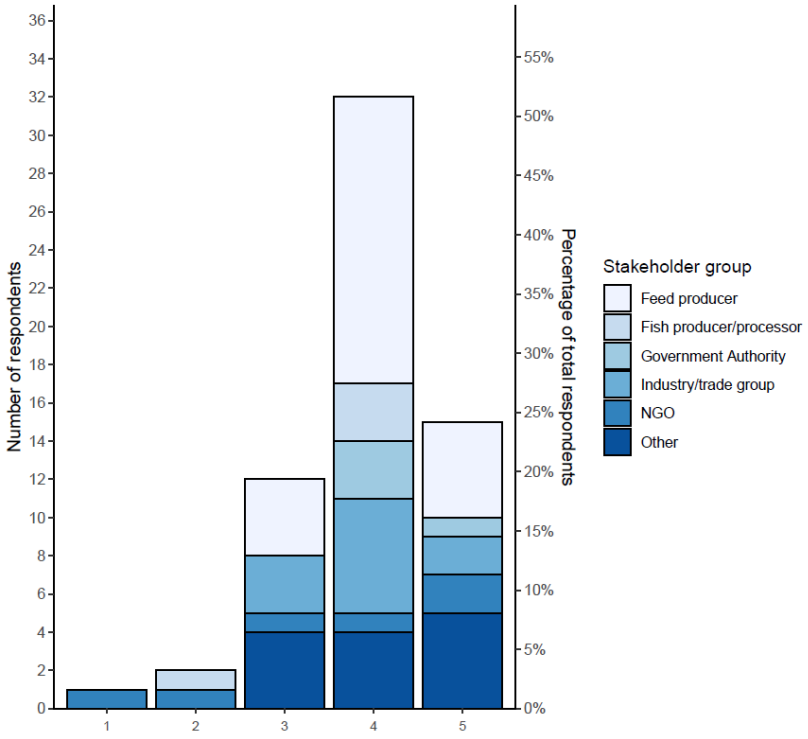


Figure 111 – Stakeholder responses to the question: Rate the following materials in terms of the security and reliability of its supply chain [Processed animal protein] (n=61)

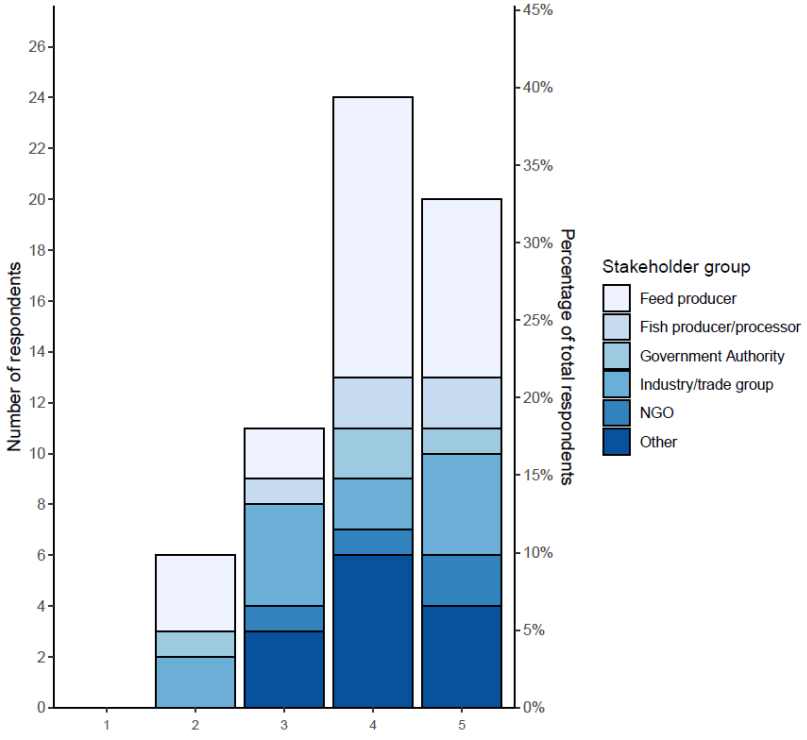


Figure 112 – Stakeholder responses to the question: Rate the following materials in terms of the security and reliability of its supply chain [Single cell protein] (n=52)

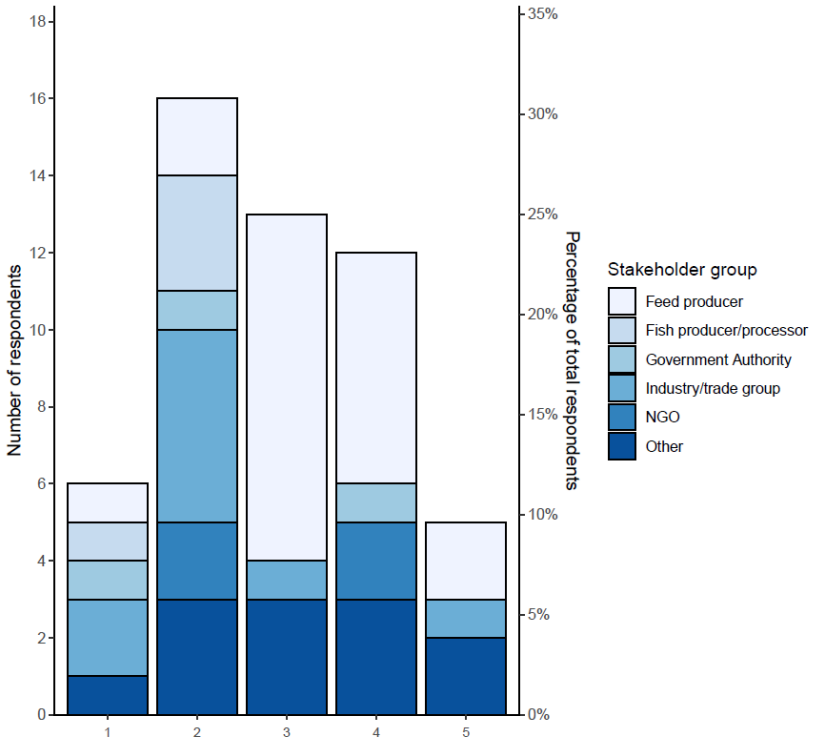


Figure 113 – Stakeholder responses to the question Rate the following materials in terms of the security and reliability of its supply chain [Krill oil] (n=57)

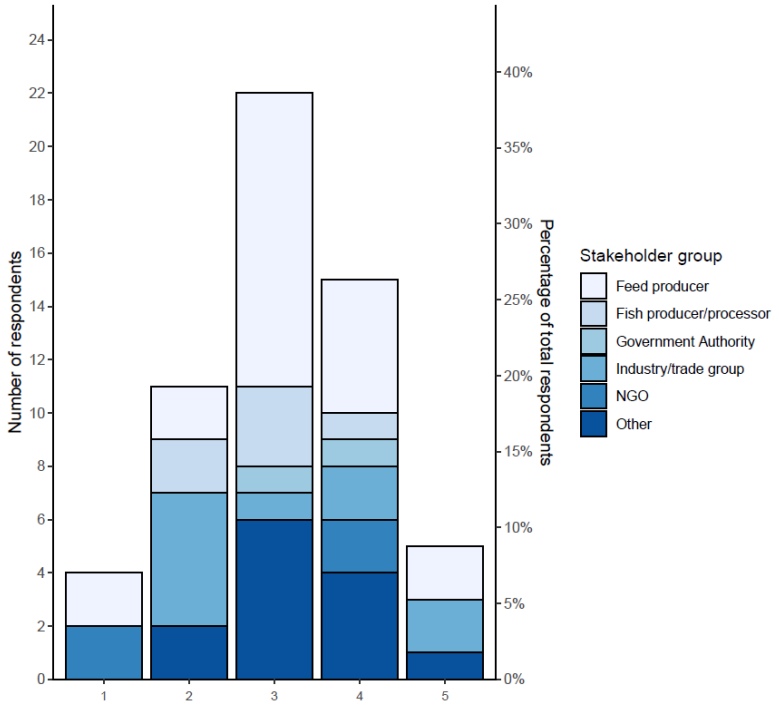


Figure 114 – Stakeholder responses to the question: Rate the following materials in terms of the security and reliability of its supply chain [Insect meal] (n=63)

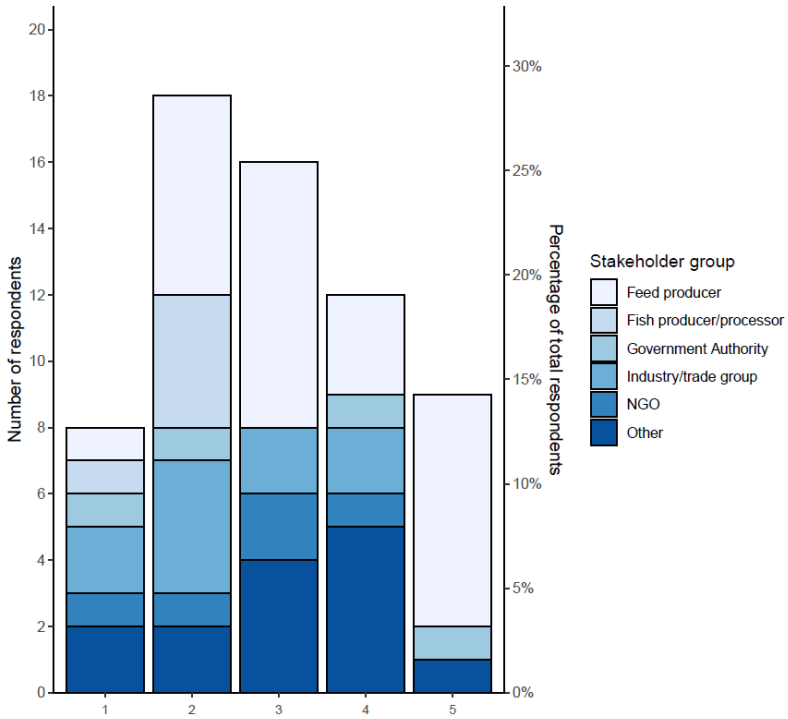


Figure 115 - Stakeholder responses to the question: Rate the following materials in terms of the security and reliability of its supply chain [Algal oil] (n = 61)

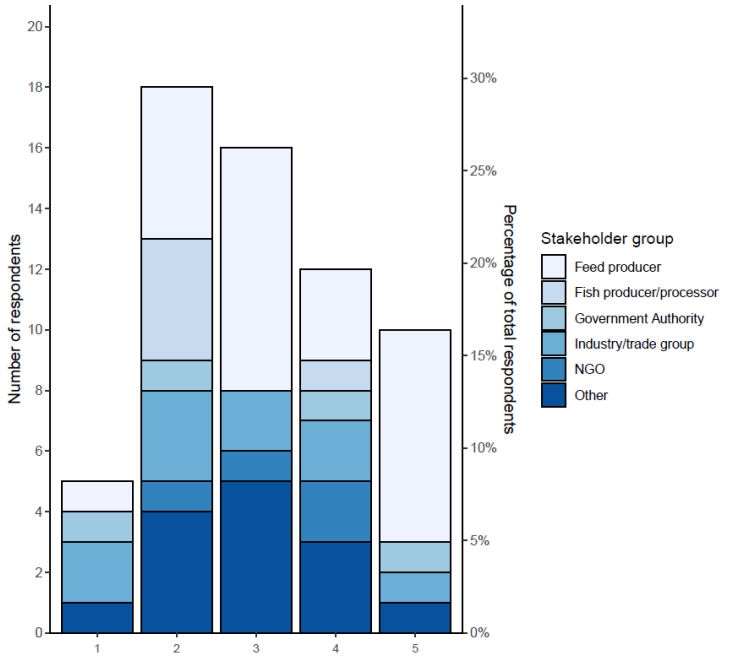
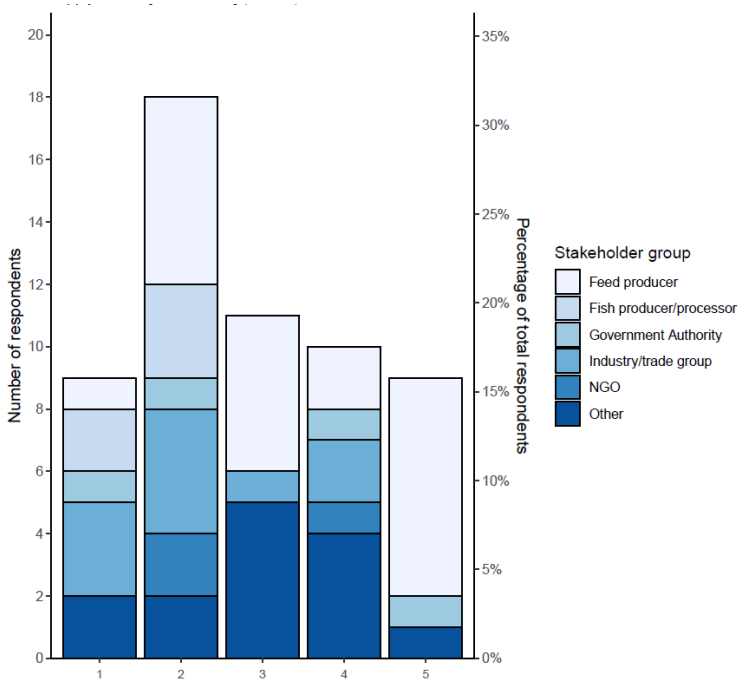


Figure 116 - Stakeholder responses to the question: Rate the following materials in terms of the security and reliability of its supply chain [Insect oil] (n = 57)



13. Annex 7 – Summary of key material information

Table 170 - Summary of key information provided for the various materials mentioned

Material	Nutritional aspects	Other beneficial aspects	Issues and limitations	Indicated inclusion levels
Fish meal	In general, high-quality fish meal produced using whole fish contains 66%–74% crude protein, 8%–11% crude lipids, and <12% ash. In contrast, fish meal produced from byproducts contains 52%–67% crude protein, 7%–14% crude lipids, and 12%–23% ash		Shows interannual variability and volatility; concerns over sustainability, rising costs; significant increases in production are unlikely to occur in the future; some growth may occur with the increased and more efficient use of fish by-products	
Fish oil	High content of long chain omega-3 polyunsaturated fatty acids		Shows interannual variability and volatility concerns; concerns over sustainability, rising costs; significant increases in production are unlikely to occur in the future; some growth may occur with the increased and more efficient use of fish by-products	In salmon feeds, vary with the life stage, ranging from 10.4% for small fish to as high as 25.8% of larger fish; in shrimp diets, ranges from 3-5% in early post-larval stages to 1-3% in grow-out feeds; in bluefin tuna diets reported crude lipid levels around 17.9%
Plant oils			Lack EPA and DHA; limitations due to nutritional profile and fatty acid deposition in fish tissues	

Material	Nutritional aspects	Other beneficial aspects	Issues and limitations	Indicated inclusion levels
Krill meal/oil	Rich in omega-3 fatty acids, phospholipids, astaxanthin and high quality proteins; natural feed attractant	Supports liver health, reduces hepatic fat accumulation and maintains or improves fillet quality and pigmentation; reduces reliance on fish meal and fish oil		
Rapeseed meal	Moderate protein content (around 39%), good amino acid profile, particularly high in lysine (1.9%) and favourable phosphorus availability (1.2%)	Low production value, global availability, and balanced amino acid profile;		
Canola oil	Low-erucic acid canola oil is rich in 18 carbon fatty acids, most notably the monounsaturated fatty acids (MUFAs), 18:1 n − 9 (oleic acid) as well as 18:2 n− 6 (linoleic acid) and 18:3 n− 3 (linolenic acid), and low in saturated fatty acids (SFAs)	Constant availability, relatively low price		
Soybean			Policy interventions and regional dynamics exert a strong influence on the soybean market. In the United States, agricultural subsidies significantly affect global prices, production patterns, and export competitiveness	
Maize/corn	Protein content of around 60-70% of dry matter, relatively low in lysine (1.1%) and phosphorus (0.4%); rich in methionine (1.4%); low fibre content (2.0%); high energy density (19.4 MJ/kg)	Steady supply and competitive price		

Material	Nutritional aspects	Other beneficial aspects	Issues and limitations	Indicated inclusion levels
Wheat gluten	Crude protein content approximately 78.2%; relatively moderate in essential amino acids like lysine (2.2%) and low phosphorus content (0.2%); high digestibility	Absence of anti-nutritional factors; supplementation; can serve as a pellet binder in aquafeeds, partially replacing indigestible binders; has a very high gross energy value	Digestibility may be reduced in carnivorous species; low palatability; carbon footprint among the highest for plant-based proteins	
Sunflower meal	High content of sulphur amino acids	Low levels of anti-nutritional factors; high palatability	Content of available lysine is poor; level of digestible energy is low due to the high fibre content	
Sunflower oil	Oil content of PUFAs ranging from 85% to 95%			
Palm oil	Rich in polyunsaturated fatty acids (PUFA, 65.7%), mainly in the form of linoleic acid (18:2 n-6, 65.7%), contains moderate levels of oleic acid (22.4%), palmitic acid (6.3%), and stearic acid (5.0%); high energy density	Oxidative stability, especially in warm climate applications	Lacks omega-3 fatty acids like EPA and DHA and provides only 0.1% linolenic acid (18:3 ω-3); contains 1.0% phospholipids, offering minimal emulsification benefits compared to marine oils	
Lupins	Crude protein content (approximately 36.3%), favourable amino acid moderate lysine content (1.8%), low methionine content (0.3%)	Lupin meal is moderately sustainable, especially when sourced locally within the EU	Presence of non-starch polysaccharides	
Faba beans	Rich in protein, carbohydrates and various essential vitamins and minerals	Has been shown to enhance the crispness and firmness of fish flesh	Contains a variety of antinutritional factors such as total phenolics, tannins, trypsin inhibitor activity, vicine, phytic acid and genistein that can affect the feed palatability as well as the bioavailability of energy and protein	

Material	Nutritional aspects	Other beneficial aspects	Issues and limitations	Indicated inclusion levels
Peas	Protein content (42–70 %); favourable amino acid profile which is similar to that of soybean meal; relatively low quantities of anti-nutritional factors	Good binding properties		
Brewer's spent grain	Rich in cellulose, hemicellulose, lignin and proteins	Is abundantly available globally		
Cottonseed meal		Much less expensive per unit of protein than fishmeal and other protein feedstuffs of animal and plant origin, including soybean meal	Contains gossypol, a compound that, at high levels, can be toxic to aquatic animals	
Poultry blood meal	High crude protein content and moderate digestibility	Compared to high-plant protein diets, poultry blood meal-based formulations can reduce intestinal inflammation and support gut health; carbon footprint is lower than that of marine-derived materials; is generally less expensive than fishmeal	Deficient in isoleucine and methionine;	
Poultry by-product meal	High crude protein content (55–70%); apparent protein digestibility coefficients range from 73% to 93% in rainbow trout	Has wide availability, favourable cost structure, and relatively high nutritional value; moderate lipid levels, and a favourable amino acid profile, particularly rich in arginine, leucine, and lysine and metabolizable energy ; lower cost compared to fishmeal;	Supplementation with specific amino acids may be required – particularly methionine and lysine; palatability issues may occur in some species at higher inclusion levels	

Material	Nutritional aspects	Other beneficial aspects	Issues and limitations	Indicated inclusion levels
Hydrolysed feather meal	Crude protein levels usually between 78% and 87%; rich in sulphur amino acids like cystine and cysteine; fat content around 5%	High availability, cost-effectiveness and sustainability potential	Low levels of essential amino acids, particularly methionine, lysine, and histidine	
Porcine by-products	Crude protein content, typically ranging from 45 to 55%; apparent protein digestibility can reach 95.9% in some species	Cost-effective, with the additional advantage of promoting health and immunity	Rich in calcium and phosphorus, though high inclusion levels may lead to increased fat deposition in fillets or reduced processing yields; methionine and lysine levels may become limiting at higher inclusion rates	
Porcine plasma and haemoglobin	Spray-dried porcine plasma contains 75–90% crude protein, low moisture content (<4.3%), and a broad spectrum of essential minerals, including sodium, potassium, phosphorus, iron, zinc, and molybdenum; amino acid profile closely resembles that of egg protein, although it may be limiting in isoleucine under certain dietary conditions; porcine haemoglobin powder typically contains over 80% crude protein and serves as a concentrated source of heme iron	The product is particularly rich in immunoglobulins and bioactive peptides that can exert systemic and gut-level immunomodulatory effects; hydrolysed haemoglobin exhibits notable antioxidant capacity and iron-chelating properties, which are linked to the composition and molecular weight of resulting peptides; this makes it a functional material, particularly relevant in fish species prone to oxidative stress or anaemia; porcine plasma and haemoglobin contribute to improved physical properties of aquafeeds, including enhanced water-holding capacity, pellet texture, and emulsification which support better feed stability and ingestion	Metallic taste and dark red colour associated with haemoglobin may require decolourisation or masking to ensure palatability	

Material	Nutritional aspects	Other beneficial aspects	Issues and limitations	Indicated inclusion levels
Porcine and poultry fats		Generally, more price-stable and cost-effective than fish oil	Contain negligible amounts of long-chain omega-3 polyunsaturated fatty acids (LC-PUFA) – such as EPA and DHA	
Insects	Crude protein level in most insects ranges from 40% to 63%, however, defatted insect meal can contain up to 83% crude protein; amino acid profile is also very good; crude lipid content of insects ranges from 8.5% to 36%; low in carbohydrates (<20%); rich in essential minerals such as calcium, phosphorus, iron, and zinc.		Negligible amounts of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), lower levels of omega-3, and higher levels of omega-6 fatty acids compared with fish meal; carbohydrate mostly in form of chitin, a polymer of glucosamine generally considered as anti-nutritional, that fish cannot digest; some species, like black soldier fly larvae, may have slightly lower levels of lysine and methionine Currently not a price-competitive raw material	
Yeast biomass	Protein content 40–55%; contains B-vitamins, nucleotides	Can improve palatability		
Fungal protein	Crude protein up to 63%, rich in essential amino acids, such as lysine	Contains immunostimulants (e.g beta-glucans) and pigments		
Bacteria	Protein content can reach up to 80% or more on a dry weight basis; high proportion of nucleic acids particularly RNA which can be as high as 20%; favourable amino acid profile		Tend to lack sulphur-containing amino acids; potential production of endotoxins by certain types of Gram-positive bacteria	

Material	Nutritional aspects	Other beneficial aspects	Issues and limitations	Indicated inclusion levels
Microalgae	Rich in crude protein (25-70% dry weight), essential fatty acids, vitamins, and minerals; often have excellent fatty acid content, particularly the presence of omega-3 and omega-6 fatty acids		Some microalgae species contain antinutritional factors, such as phenolic compounds and polysaccharides, which can hinder nutrient absorption and digestibility	
Macroalgae	Protein content between 10-30%; relative to total amino acids, most species have a proportion of essential amino acids equivalent to or greater than the proportion thereof in traditional agricultural crops and fishmeal		Dietary fibre limits the digestibility of the algal protein fractions and affects the overall nutritional value	

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