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THE GROWING THREAT OF CARNIVOROUS AQUACULTURE

© Ashley Christiano

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COMPASSION IN WORLD FARMING INTERNATIONAL (CIWF) is the leading international farm animal welfare charity. It was founded in 1967 by British dairy farmer Peter Roberts and now operates globally, including in Europe, the US, Asia and Africa. Our mission is to end factory farming. We work with policymakers, food businesses and civil society to protect animals and the environment, driving shifts to regenerative and sustainable food systems that produce nutritious food, respect animal welfare, and work with nature. This report was produced by MarFishEco Fisheries Consultants Ltd in collaboration with CIWF.

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Executive summary

Aquaculture is one of the fastest-growing food production sectors worldwide. Often presented as a solution to rising seafood demand, its continued expansion, particularly of carnivorous species, raises serious environmental, food security, social, and animal welfare concerns.

This rapid expansion has come at a huge cost. Intensive farming systems have been linked to water pollution, disease outbreaks, chemical inputs, and escapes of non-native species, while welfare standards for farmed fish remain weak.

Feed-intensive aquaculture growth depends on wild-capture forage fisheries to produce fishmeal and fish oil (FMFO). This has consequences that include overfishing, weakened marine ecosystems, and threats to the food security of coastal communities that rely on these fish for direct consumption.

Ecological footprint of European seafood consumption will increase

Currently, most European aquaculture production comes from a handful of carnivorous species. Our analysis on future projections of production of the top carnivorous and omnivorous species – such as Atlantic bluefin tuna, Atlantic salmon and Rainbow trout –shows an increase of 30% by 2040. This would create an even more devastating reliance on the capture of wild-caught fish to produce FMFO – an increase of 70% by 2040. This projected rise would simply exacerbate the negative ecological, social, and animal welfare impacts.

Spain illustrates these pressures most clearly. As one of Europe's top FMFO consumers, Spain sourced FMFO from many countries that have elevated risks of illegal, unreported, or unregulated fishing (IUU fishing) and limited sustainable fishing practices. Spain is also pushing the expansion of aquaculture into new feed-intensive species. The most striking example is industrial-scale octopus farming.

The potential emergence of octopus farming has drawn immense international opposition, reflecting widespread recognition that farming such a highly sentient, solitary, and carnivorous species is incompatible with welfare, sustainability, and food security objectives.

Transitioning to a more sustainable food system

Aquaculture does not have to follow a feed-intensive path. Farming low-trophic species such as mussels, oysters, carp, and seaweed can provide a reliable source of healthy protein at minimal environmental cost, while even delivering ecological benefits such as carbon sequestration, water filtration, and habitat creation. Alternatives to wild-capture forage fisheries are continually evolving – ranging from seafood by-products to algae, plant-based ingredients, insect meals, and single-cell proteins.

While these innovations may reduce dependence on wild-caught forage fish, they do not resolve the fundamental problems of farming high-trophic carnivorous species that require high-quality protein inputs. Moreover, many of these alternatives face significant challenges in terms of scalability and widespread adoption, and several carry their own sustainability trade-offs.

The future of aquaculture must be defined by a decisive transition away from intensive, high-trophic, feed-based systems towards low-trophic, extensive systems focused on filter-feeding or herbivorous organisms. Achieving this will require coordinated national, EU and global policies that embed animal welfare, food security, and ecological integrity at the core of aquaculture development. At EU level, these priorities align closely with the Strategic Guidelines for Sustainable Aquaculture.

The following three strategic priorities should be adopted:

- Shift species portfolios: Phase out the expansion of carnivorous aquaculture reliant on wild-caught forage fish.
- Reform aquafeeds: Phase out the use of purpose-caught wild fish, including forage fish, mesopelagic fish, krill, and other species for feed.
- Strengthen animal welfare: Ensure that welfare protections are extended across the entire production cycle. New species should only be farmed if their behavioural and physiological needs can be met in captivity.

Only by embracing these changes can aquaculture evolve into a more sustainable food system – one that protects animal welfare, safeguards marine ecosystems, and strengthens global food security.

Key insights on current FMFO trade:

- In 2020, the top global consumers of FMFO were China, Japan, Vietnam, Turkey, and Norway, while the top exporters were Peru, Chile, Denmark, Morocco, and the United States.
- In Europe, the top FMFO consumers in 2020 were the United Kingdom (UK), Greece, Germany, Spain, and Denmark, broadly aligned with the region's leading aquaculture industries. These are consistently supplied by Denmark, Morocco, and Peru. These trade flows show how Europe's aquaculture sector is tightly interconnected with global forage fisheries, carrying both ecological and social consequences.
- Europe's top exporters of FMFO are Denmark, Germany, the Netherlands, Spain, and the UK.
- Since 1985, 78 new species have been introduced into European aquaculture, nearly 70% of which depend on animal-based feeds, raising serious sustainability concerns, as it deepens reliance on finite wild fish resources.
- In 2020, Spain sourced FMFO from 26 countries, the largest network of source countries among all European countries, and its sourcing practices were characterised by relatively high IUU fishing risk and poor performance on sustainable fishing practices (MSC-certified fisheries).

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Key data on European carnivorous aquaculture expansion

- Production of the top ten carnivorous and omnivorous species could reach 860,450 tonnes by 2040, a 30% increase from 2023.
- The UK, Greece, and Spain are predicted to see the highest levels of carnivorous aquaculture production.
- Demand for wild-capture forage fish to produce FMFO is anticipated to climb to 2.5 million tonnes, or between 83.3 and 192 billion individual fish, by 2040 – an increase of 70% from 2023.
- Nueva Pescanova's proposed octopus farm in Spain would produce around 3,000 tonnes of octopus each year, equivalent to approximately one million individual octopuses. This could require up to 28,000 tonnes of forage fish as feed in the first year alone, between 0.9 and 2.1 billion individual fish.
- Projections show that the output of this farm could more than triple to 3.2 million octopuses per year by 2040 – requiring up to 90,700 tonnes of forage fish.

Glossary

Alternative feeds: Non-FMFO ingredients (e.g., seafood by-products, plant proteins/oils, algae, insect meals, single-cell proteins) intended to reduce reliance on wild fish in aquaculture diets.

Animal welfare (aquatic): The physical and behavioural well-being of farmed aquatic animals (e.g., stocking density, water quality, enrichment, handling/transport, stunning and slaughter).

Aquaculture: Farming of aquatic organisms (fish, molluscs, crustaceans, seaweeds) involving human intervention in breeding, rearing, or stocking.

Aquafeed: Formulated feed for farmed aquatic species; typically includes protein and lipid sources (FMFO, plant ingredients, and alternatives).

Blue carbon: Carbon captured and stored by coastal and marine ecosystems (e.g., seagrass, mangroves, macroalgae/seaweed farms).

Carbon sequestration (seaweed/shellfish contexts): The uptake and retention of carbon by cultured macroalgae and, indirectly, by ecosystems influenced by low-trophic aquaculture.

Carnivorous species: Farmed species whose natural diets are primarily animal-based (e.g., salmon, trout, seabass, seabream, octopus), generally more feed-intensive.

eFCR (economic or apparent Feed Conversion Ratio): Feed offered divided by harvested biomass (wet weight). Lower values indicate more efficient feed use.

EIA (Environmental Impact Assessment): Pre-approval analysis of expected environmental effects of a project (e.g., an aquaculture facility), including mitigation measures.

EU (European Union): Political and economic union of European member states.

FIFO (Fish-In Fish-Out): Ratio expressing the mass of wild fish used to produce one mass unit of farmed fish; an indicator of reliance on reduction fisheries.

Fishmeal (FM): Protein-rich powder rendered from whole fish and/or by-products; key ingredient in feeds for many carnivorous species.

Fish oil (FO): Lipid fraction rendered from whole fish and/or by-products, valued for long-chain omega-3 fatty acids in aquafeeds.

FMFO (Fishmeal & Fish Oil): Collective term for fishmeal and fish oil; central to the report's analysis of feed dependency and trade.

Forage fish: Small, schooling, lower-trophic species (e.g., anchovy, sardine, herring, mackerel) targeted by reduction fisheries and critical prey for predators.

IMTA (Integrated Multi-Trophic Aquaculture): Co-culturing species at different trophic levels (e.g., finfish with shellfish and seaweeds) to recycle nutrients and lower impacts.

Inclusion rate (FM/FO): Percentage of fishmeal or fish oil in a feed formulation (by weight). Lower inclusion rates generally decrease reliance on wild fish.

IUU fishing: Illegal, unreported, and unregulated fishing that undermines and elevates ecological and social risks.

Low-trophic aquaculture:	Farming species low on the food chain (e.g., mussels, oysters, carp, seaweed) with comparatively low external feed inputs and, in some cases, ecological co-benefits.
Megajoule (MJ):	SI unit of energy equal to 10^6 joules. In aquaculture LCAs, it typically denotes energy use per unit of product.
MSC (Marine Stewardship Council) certification:	Fishery certification assessing sustainability performance; often used as a proxyindicator for “sustainable fishing practices” in trade analysis.
Omnivorous species:	Farmed species with mixed diets (plant and animal matter), typically with lower FMFO needs than strict carnivores.
Prediction interval (PI):	Statistical range that is expected to contain a specified proportion of future observations from a model (e.g., 90% PI for projected production).
PSMA (Port State Measures Agreement):	International treaty aiming to prevent IUU-caught fish from entering ports and markets through minimum inspection and enforcement standards.
RAS (Recirculating Aquaculture Systems):	Land-based, tank systems that treat and reuse water; can reduce effluents and escapes but require energy and capital.
Reduction fisheries:	Fisheries primarily targeting forage fish for rendering into FMFO rather than for direct human consumption.
RFMO (Regional Fisheries Management Organisation):	Intergovernmental body managing fisheries in a region/high seas; “compliance with RFMO port obligations” is used as an indicator in your sourcing risk analysis.
Seacage / net-pen aquaculture:	Open-water cages for finfish; exposure to surrounding environment can elevate risks of escapes, disease transfer, and local benthic impacts.
Small pelagics:	Collective term for many forage fish species inhabiting the upper water column (e.g., sardine, anchovy); heavily represented in FMFO supply chains.
Stocking density:	Biomass (or number) of animals per unit volume/area; a key welfare and environmental management parameter.
Trophic level:	Position in a food web-based on diet; higher trophic levels (carnivores) generally require richer feeds and more FMFO.
Wild-capture fisheries:	Harvest of naturally occurring fish and invertebrates (as distinct from aquaculture). Forage fisheries are a subset often supplying FMFO.
90% quantile range:	The interval between the 5th and 95th percentiles of an estimated distribution. It captures the central 90% of possible values, providing an indication of the uncertainty around an estimate.

Objectives

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Aquaculture is often presented as a solution to rising seafood demand, yet the sector's continued expansion, particularly of carnivorous species, raises profound ecological, social, and ethical concerns. These concerns are becoming more acute as Europe considers the farming of new species such as octopus, exemplified by Nueva Pescanova's proposal to build the world's first industrial octopus farm in Spain. To better understand the risks posed by these developments and their implications for marine ecosystems and food security, this report pursues three main objectives:

1. Assess historic trends:

Using the FAO FishStatJ Global Aquaculture Production dataset (1), the development of aquaculture production was evaluated, and more specifically carnivorous aquaculture, both globally and in Europe specifically, to understand how the sector has evolved and its overall impact.

2. Model future trajectories:

The assessment of historic trends in carnivorous aquaculture production was used to develop statistical models to project future production of carnivorous aquaculture in Europe and associated demand for wild-capture forage fish. Similar models were used to estimate potential output from Nueva Pescanova's proposed octopus farm under varying feed scenarios.

3. Analyse trade flows:

Using the ARTIS dataset (2), global trade of FMFO, identifying the major producing and consuming countries, to assess how sourcing patterns shape ecological and social impacts worldwide and within Europe, with particular attention to Spain given the proposed octopus farm.

Together, these analyses provide a foundation for evaluating the risks of carnivorous aquaculture and how those risks may intensify with further expansion. They also stress the importance of policies that not only reduce reliance on high-impact, feed-intensive systems, but also promote a transition toward low-trophic, sustainable aquaculture while ensuring responsible sourcing of FMFO where its use remains necessary .

Aquaculture – a growing, global industry

Aquaculture, the farming of aquatic organisms (e.g., fish, molluscs, crustaceans and aquatic plants), has become a cornerstone of the global food system (3). Unlike capture fisheries, which harvest wild stocks, aquaculture involves human intervention in the rearing process to enhance production, such as stocking, feeding, protection from predators, and habitat management (4). Since the late 1980s, aquaculture has expanded rapidly reaching an all-time high of approximately 133 million MT (metric tonnes) in 2023 (Figure 1), a year in which it provided more than half of global aquatic food (1,4).

In 2022 aquaculture production surpassed wild capture fisheries (94 million MT and 91 MT of aquatic animals respectively in 2022) (4). This growth is often celebrated as a key solution to global food and nutrition security, especially in the face of stagnating wild capture fisheries (4). However, while the rise of aquaculture signals progress in terms of production, it also brings with it a suite of ecological, social, and ethical concerns that challenge this "blue revolution" (5).

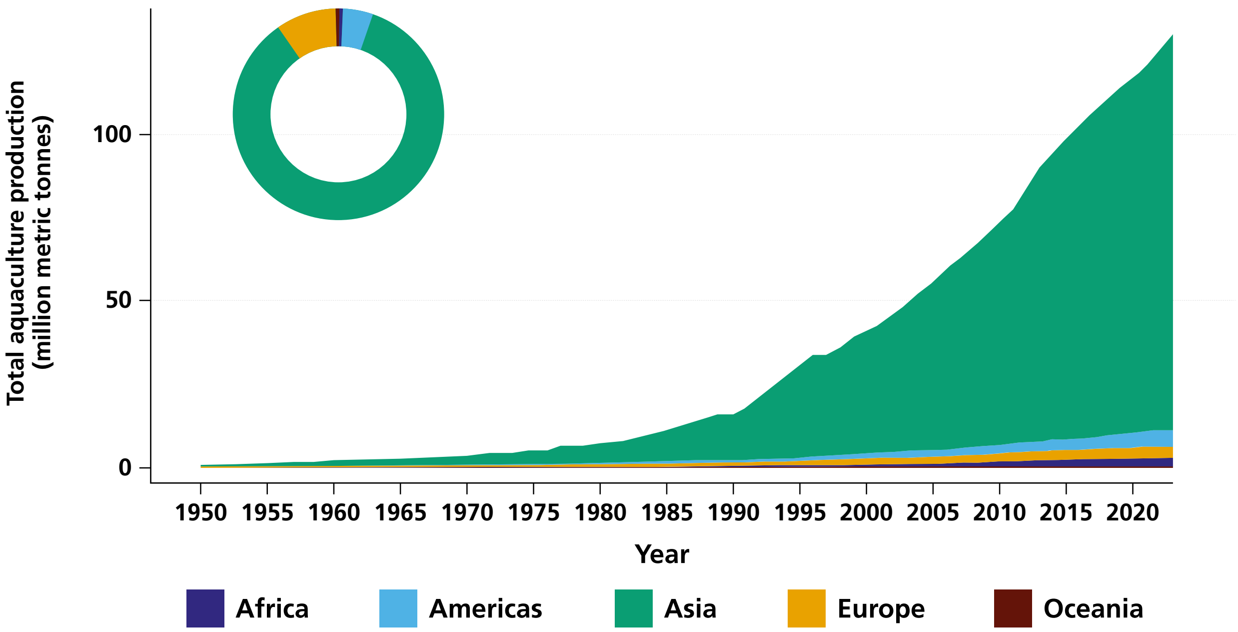

Figure 1. Global aquaculture production from 1950 to 2023 by continent. While Oceania is included in the figure, its values are not easily visible because they are so low. The pie chart represents average annual proportions of global aquaculture production by continent between 1950 and 2023. Data source: FAO FishStatJ – Global Aquaculture Production dataset.

Growth in aquaculture has varied considerably geographically, reflecting differences in investment, technology, consumer demand, and management, all of which influence farming scales and performance (6). Global growth in aquaculture production has been driven primarily by Asia, which accounted for an annual average of 85.2% of production between 1950 and 2023, followed by Europe (9.3%) and the Americas (4.37%). Africa and Oceania contributed relatively small shares to global production, annually averaging only 0.8% and 0.3% respectively.

Over 500 different aquatic species are farmed globally. About 70% of global aquaculture production consists of finfish and aquatic plants (Figure 2). The top species groups based on average annual production are seaweeds, bivalves, tilapia, and various carp species (Figure 3).

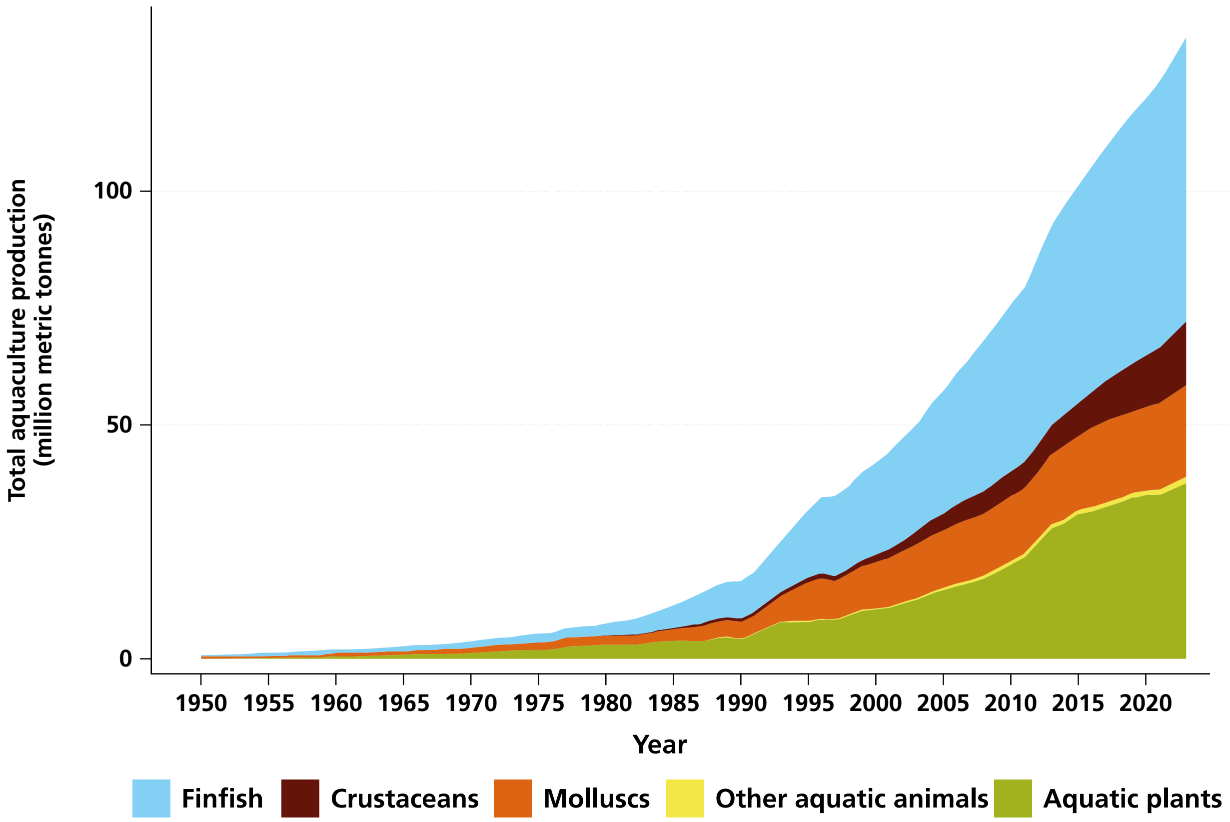

Figure 2. Global aquaculture production from 1950 to 2023 by species groups. Data source: FAO FishStatJ – Global Aquaculture Production dataset.

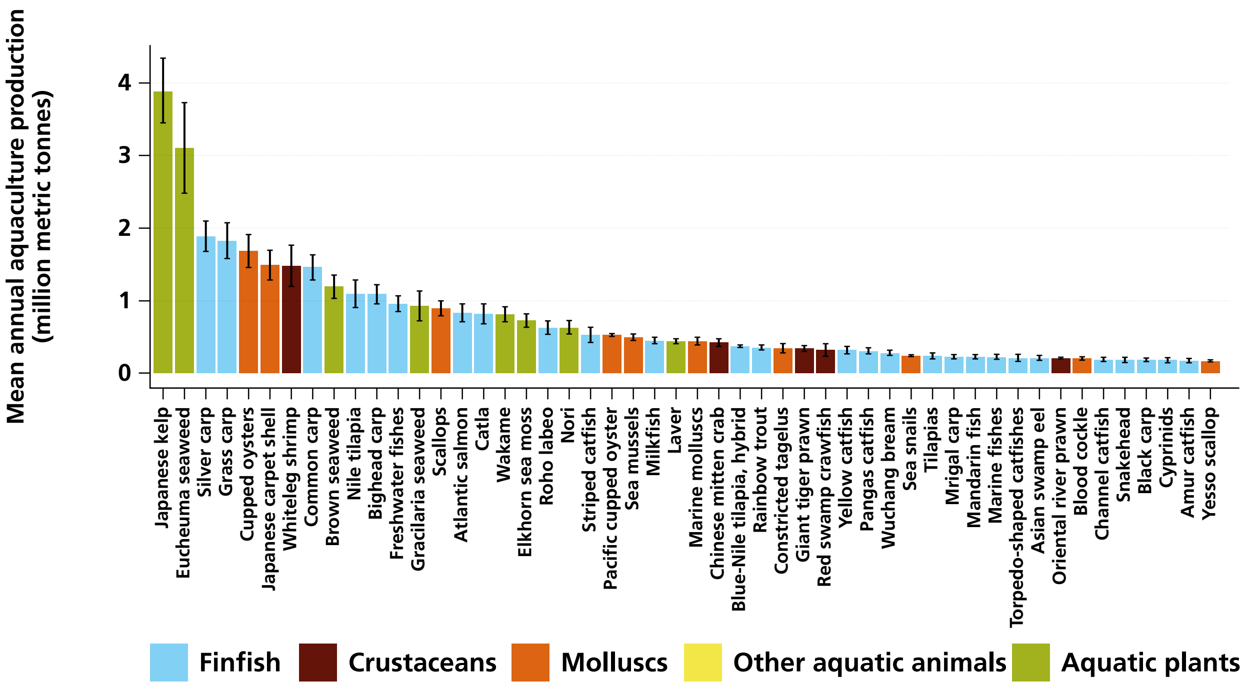

Figure 3. Average annual global aquaculture production of the top 50 species farmed globally from 1950 to 2023 by broad aquatic organism categories. Error bars show the standard error of the mean. Data source: FAO FishStatJ – Global Aquaculture Production dataset.

Aquaculture growth in Europe – driven by Norway

Similar to global trends in aquaculture production, Europe[1] has shown a steady increase in growth between 1950 and 2023 (Figure 4A and 4B), much of which has been driven by Norway since the mid-1990s.

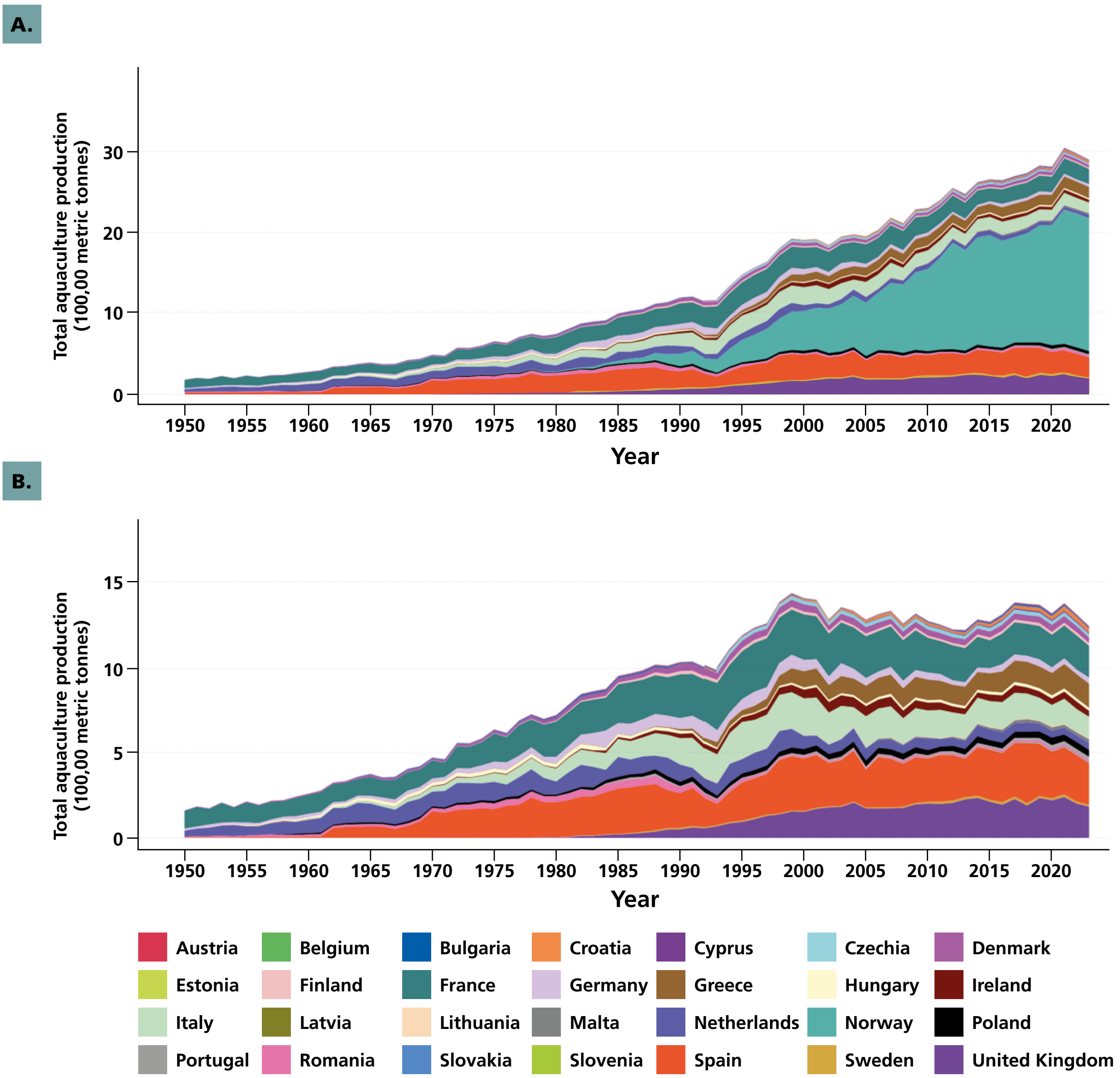

Figure 4. Aquaculture production by European country with (A) and without (B) Norway. Data source: FAO FishStatJ – Global Aquaculture Production dataset.

Excluding the significant growth that has been driven by Norway, aquaculture growth in Europe has slowed since the late 1990s (Figure 4B) with most growth now being driven by Spain (4,403 MT/year), the United Kingdom (3,842 MT/year), Italy (2,886 MT/year), Greece (2,226 MT/year) and France (2,015 MT/year) (Figure 5 and Annex Table 3).

1 Europe includes EU Member States, the United Kingdom, and Norway.

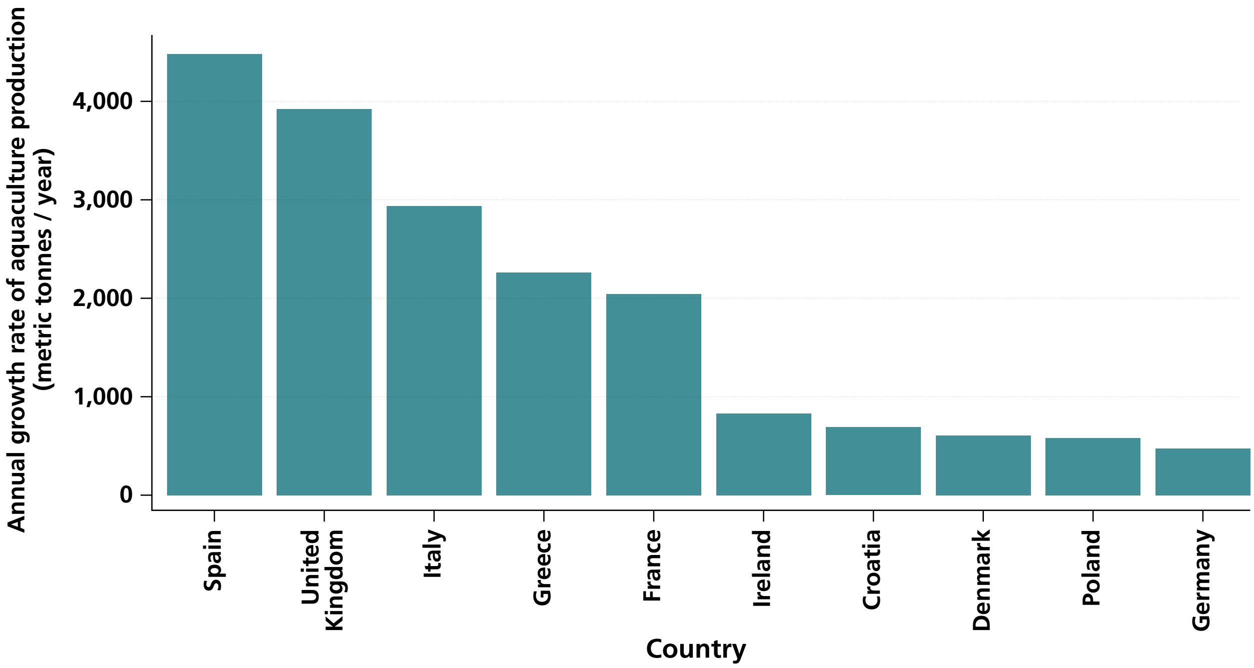

Figure 5. Average annual growth rate of aquaculture production by European country between 1950 and 2023. Only the top ten European countries are visualised. For a list of annual growth rates of aquaculture production for all European countries see Annex Table 3. Norway has been removed from the graphic for easier visualisation. Data source: FAO FishStatJ – Global Aquaculture Production dataset.

Most of Europe's[2] aquaculture production is concentrated in molluscs and finfish (Figure 6). Among the molluscs farmed in Europe, Blue mussel (*Mytilus edulis*), Pacific cupped oysters (*Crassostrea gigas*), and European flat oyster (*Ostrea edulis*), on average have the highest annual aquaculture production. Among the finfish farmed in Europe, Rainbow trout (*Oncorhynchus mykiss*), Atlantic salmon (*Salmo salar*), and Common carp (*Cyprinus carpio*) on average have the highest annual aquaculture production.

Aquaculture in Norway

Norway has dominated European aquaculture since the 1990s (Figure 4A). In fact, Norway experienced the highest average annual growth rate in aquaculture production (21,952 MT/year) from 1950 to 2023 in Europe (Table 3). Much of its production comes from salmonids. In 2023, Atlantic salmon reached 1,542,480 MT (93% of aquaculture production) and Rainbow trout reached 90,022 MT (5% of aquaculture production), together accounting for 98% of Norway's aquaculture production.

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2 Europe includes EU Member States and the United Kingdom.

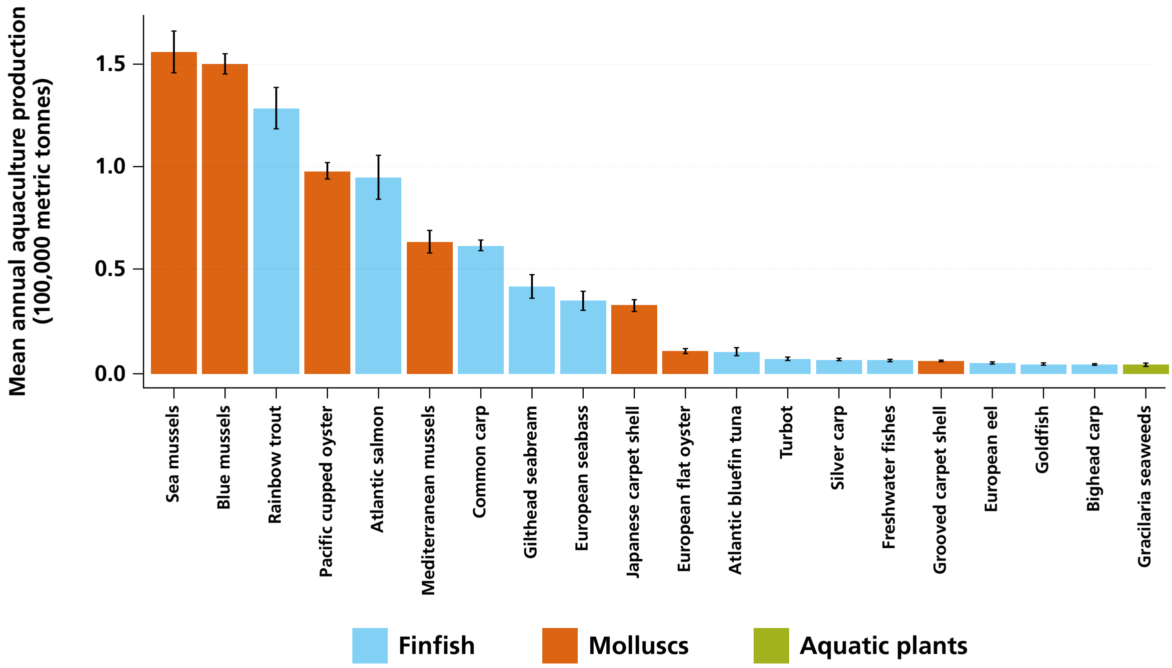

Figure 6. Average annual aquaculture of the top 20 species farmed in Europe between 1950 and 2023 by broad aquatic organism categories. Species produced in Norway have been removed from the graphic. Data source: FAO FishStatJ – Global Aquaculture Production dataset.

Risk & reward in carnivorous aquaculture

The production of carnivorous species has been increasing over time, particularly in Europe and Asia (Figure 7). A significant share (approximately 61% in 2023[3]) of European aquaculture is focused on a few, high-value, carnivorous species, including Atlantic salmon (*Salmo salar*), Rainbow trout (*Oncorhynchus mykiss*), European seabass (*Dicentrarchus labrax*), and Gilthead seabream (*Sparus aurata*) (Figure 6), which require high-quality, nutrient-dense feeds. A primary component of these feeds is fishmeal and fish oil (FMFO), which is largely sourced from wild-caught forage fish like anchovy, sardine, herring, and mackerel[4] (4).

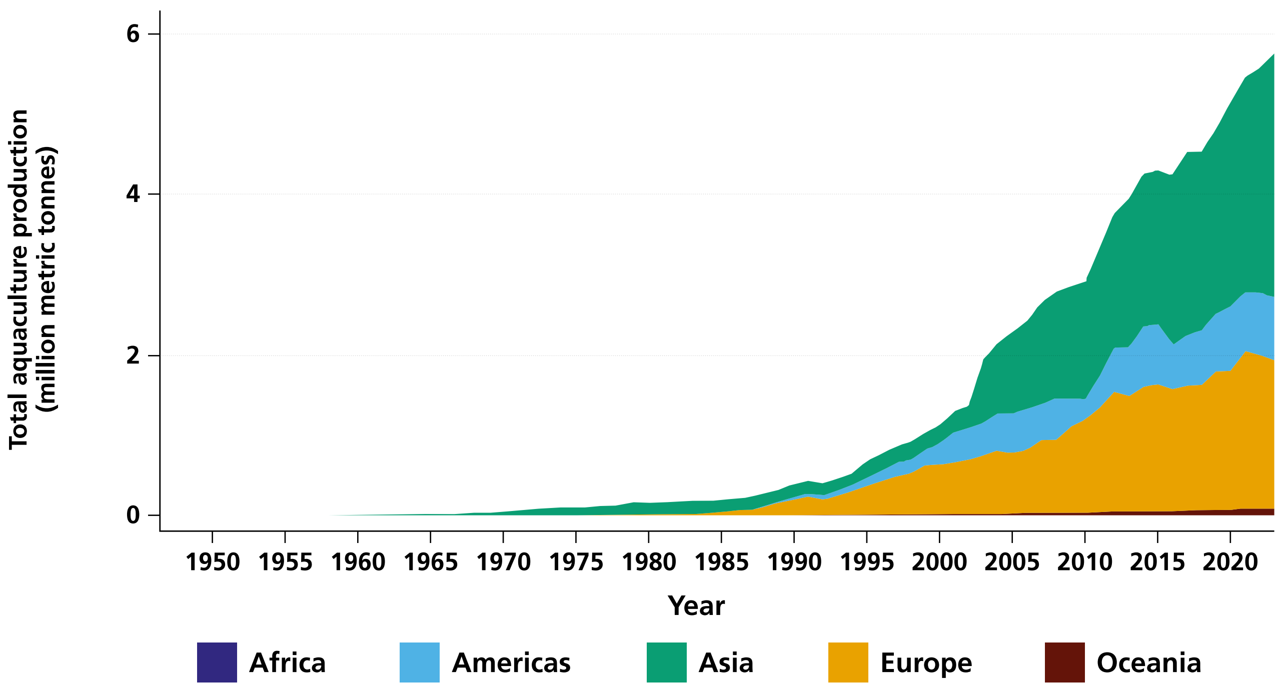

Figure 7. Aquaculture production of carnivorous species from 1950 to 2023 by continent. While Africa is included in the figure, its values are not easily visible because they are so low. Only carnivorous species that comprise 90% of annual global aquaculture production are included. Data source: FAO FishStatJ – Global Aquaculture Production dataset.

3 This only includes species that comprise 90% of global aquaculture production.

4 FMFO is also produced from by-products of wild and farmed fish as well as a range of plant sources, some novel animal proteins (e.g., insect meals), and microbial products (e.g. micro-algae and single-celled proteins) (4,7)

While carnivorous aquaculture may provide a relatively consistent supply of high-value, consumer-preferred species to ever hungry markets (8), support coastal economies and employment (4), and offer a potential solution to rising seafood demands as wild fisheries stagnate (4), these benefits are not without significant trade-offs (Figure 8).

Aquaculture production – particularly in carnivorous aquaculture – can result in significant environmental harm (7). In open-water systems, uneaten feed, fish waste, parasites, and chemical inputs (such as antibiotics) are released directly into surrounding waters. These discharges can lead to eutrophication, habitat degradation, and the proliferation of disease or antibiotic-resistant bacteria, especially in areas lacking water recycling or effective containment (9). An additional risk related to any open-water aquaculture system is the escape of farmed species.

These escapees can compete with or interbreed with wild populations, potentially leading to the spread of disease, reduced genetic diversity, and long-term impacts on the fitness and resilience of native stocks (5). Whilst land-based recirculating aquaculture systems (RAS) can overcome some of these problems, their energy use and associated greenhouse gas (GHG) emissions can be substantial, often undermining their benefits and hindering widespread adoption (10). For example, it has been estimated RAS energy requirements would be nearly eight times greater than a flow-through system and over 31 times that of a cage system (11). Similarly, farming Atlantic salmon in RAS has been reported to require more than three times the energy compared to conventional sea pen farming (12,13). Moreover, CO^2 emissions per kg of product may be anywhere from 2 to 13 times higher in land-based recirculating systems than for other farming methods (14). The use of these systems for the grow-out phase of aquaculture production is highly intensive and heavily dependent on technology, biosecurity, barren and sterile rearing environments, and high stocking densities due to underlying economic imperatives with proven negative impacts on the animals (15,16).

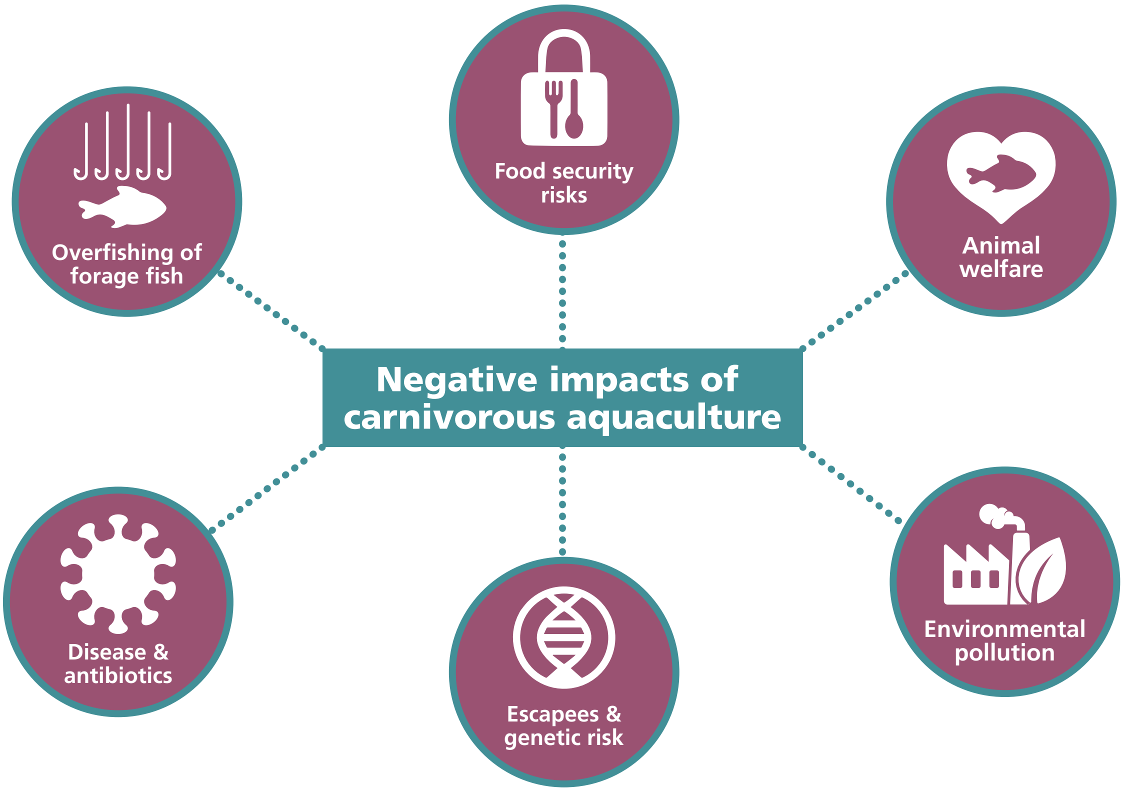

Figure 8. Negative impacts of carnivorous aquaculture. While these impacts are not unique to carnivorous aquaculture, they are more prevalent in carnivorous aquaculture systems.

The feeds used in carnivorous aquaculture operations often rely heavily on wild-caught forage fish. Carnivorous aquaculture operations therefore impose greater ecological and social costs than systems that farm herbivorous or omnivorous species. Forage fish species play a crucial ecological role transferring energy from primary producers to higher trophic-level species including large fish, marine mammals, and seabirds (17). Additionally, in many countries, forage fish are a critical source of both dietary protein for human consumption and an important source of livelihood, with harvest and processing providing critical income for coastal communities (18). For example, in many regions such as West Africa, Southeast Asia, and South America from where fisheries supply much of the fish used for feed, forage fish are a critical source of both dietary protein for human consumption and an important source of livelihood, with harvest and processing providing critical income for coastal communities (19,20). Using forage fish to produce FMFO for carnivorous aquaculture[5], rather than people, creates direct competition with human consumption and threatens the food security (and livelihoods) of coastal communities that depend on them. It is estimated that up to 90% of the wild fish used in aquafeeds could instead be consumed directly by humans. Moreover, carnivorous aquaculture mainly produces high-trophic, high-value products for premium markets, with limited direct contribution to food and nutrition security (22).

Beyond the environmental impacts of carnivorous aquaculture operations, the welfare of fish and other aquatic animals in intensive farms is seriously compromised. Animal welfare standards and enforcement vary widely across aquaculture systems. Often, fish are kept at high stocking densities in barren enclosures that restrict natural behaviour and contribute to stress, disease, and high mortality rates that can range from 15% to 80% for some of the most commonly farmed species (23). Routine practices like netting, crowding, and pumping expose fish to repeated stressors (24). Transport, which may last hours or days, further compromises welfare through handling, environmental changes, and poor water quality (25). Most farmed fish worldwide are killed inhumanely, often by asphyxiation in air or ice slurry, or during gutting and processing while still conscious (26). These methods prolong suffering. Although humane stunning techniques, such as electrical or percussive stunning, exist and can reduce pain, widespread adoption in the industry remains limited (27).

Despite being recognised as sentient under Article 13 of the Treaty on the Functioning of the European Union (TFEU) (28), many fish are slaughtered without prior stunning, raising serious ethical concerns about current aquaculture practices (23). In addition, the welfare issue is beyond farmed animals themselves. The wild-caught fish used to produce feed suffer during capture and slaughter, with scientific estimates suggesting that between 500 and 1,100 billion fish are killed each year for this purpose (29). These vast numbers represent a massive and overlooked welfare crisis.


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5 While most FMFO is used in aquaculture, smaller shares support livestock and pet food production, and FO is increasingly used in nutraceuticals and other products (21).

Trade of FMFO

With the rapid and continued expansion of the global aquaculture industry, significant demands have been placed on wild-capture fish stocks (30). The magnitude of this demand is influenced by the species being farmed, their dietary protein requirements, and the efficiency with which feed is converted into edible biomass, typically measured through feed conversion ratios (FCR) and fish-in fish-out (FIFO) metrics (31). However, global trade in FMFO derived from wild-capture fisheries, although highly variable, has exhibited a general long-term decline (Figure 9). This trend likely reflects the increasing substitution of FMFO with alternative feed ingredients in aquaculture and agriculture[6] diets, improved farming practices, management measures that have limited catch volumes to help stabilise exploitation rates and natural ecological variability in key forage fisheries such as the Peruvian anchoveta (*Engraulis ringens*) – the world's largest single species forage fish fishery which is heavily influenced by El Niño climate cycles (31–33).

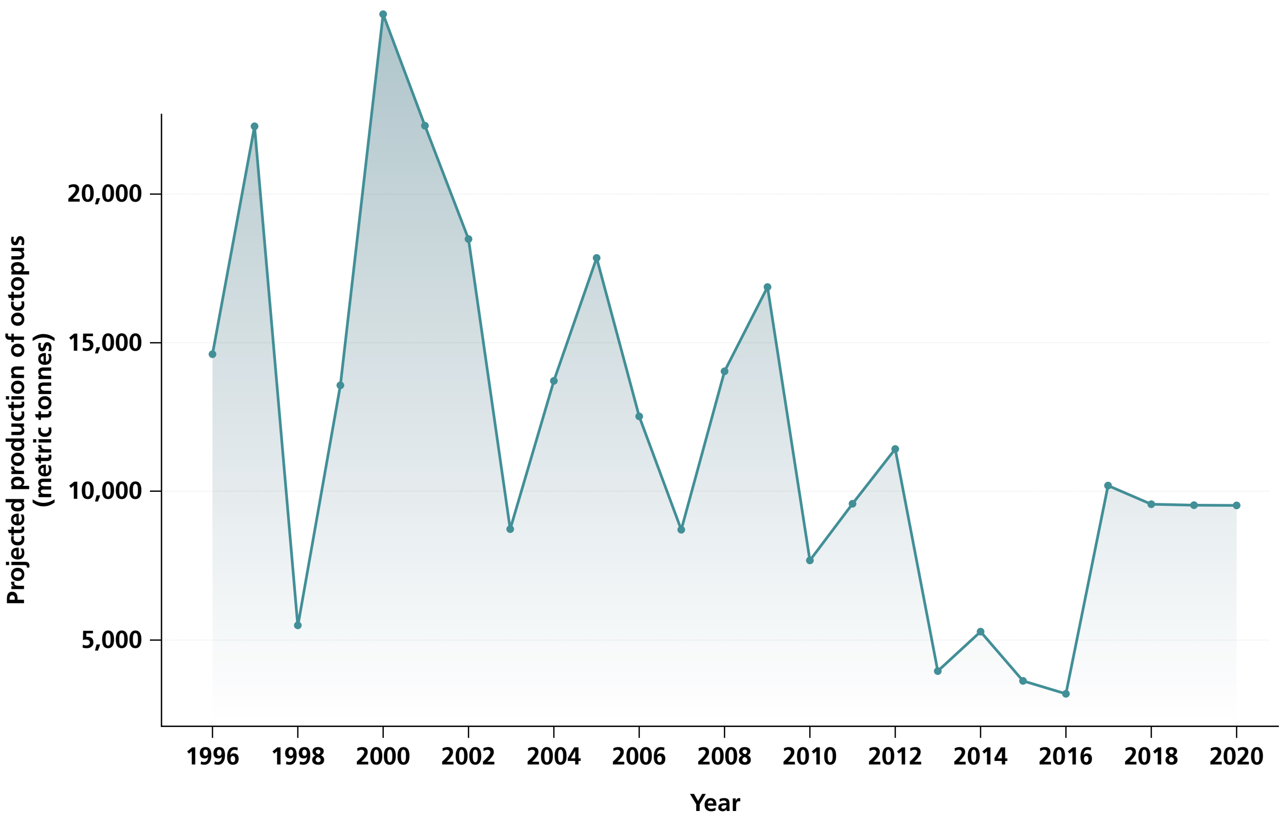

Figure 9. Global trade of FMFO derived from wild-capture fisheries from 1996 to 2020. Data source: ARTIS dataset.

In 2020, the top five global importers of FMFO derived from wild-capture fisheries were China (1.1 million MT), Japan (160,933 MT), Vietnam (151,640 MT), Turkey (141,563 MT), and Norway (137,787 MT) while the top five global exporters were Peru (858,561 MT), Chile (234,958), Denmark (177,253 MT), Morocco (162,658 MT), and the United States (135,276 MT) (Figure 10).

Using FMFO imports and exports as proxies for consumers and producers, the main importers are leading aquaculture producers, for example China, where farmed aquaculture production is dominated by carp species (*Cyprinus spp.*), and Norway, the world's largest producer of farmed Atlantic salmon. Similarly, the main exporters mirror the major reduction fisheries. Peru's anchoveta fishery, the largest global source of FMFO (32), and Morocco's sardinella (*Sardinella aurita* and *Sardinella maderensis*) fishery, both supply substantial volumes to FMFO despite their

6 FMFO is also a significant component of agricultural animal feeds (21).

potential importance for food and nutrition security, raising ongoing food security concerns (19,20). Denmark's Blue whiting (*Micromesistius poutassou*) fishery, once a key source of feed for Europe's farmed salmon industry, lost MSC-certification in 2020 following prolonged quota disputes and failure to align catch shares with scientific advice, raising concerns over ecosystem impacts and the diversion of forage fish into reduction fisheries (34). Similarly, Denmark's Sandeel (*Ammodytes marinus*) fishery, another important FMFO source, has also come under increasing scrutiny for its ecological impacts. More recently, the United Kingdom banned Sandeel fishing in its waters to protect seabirds and marine mammals (35).

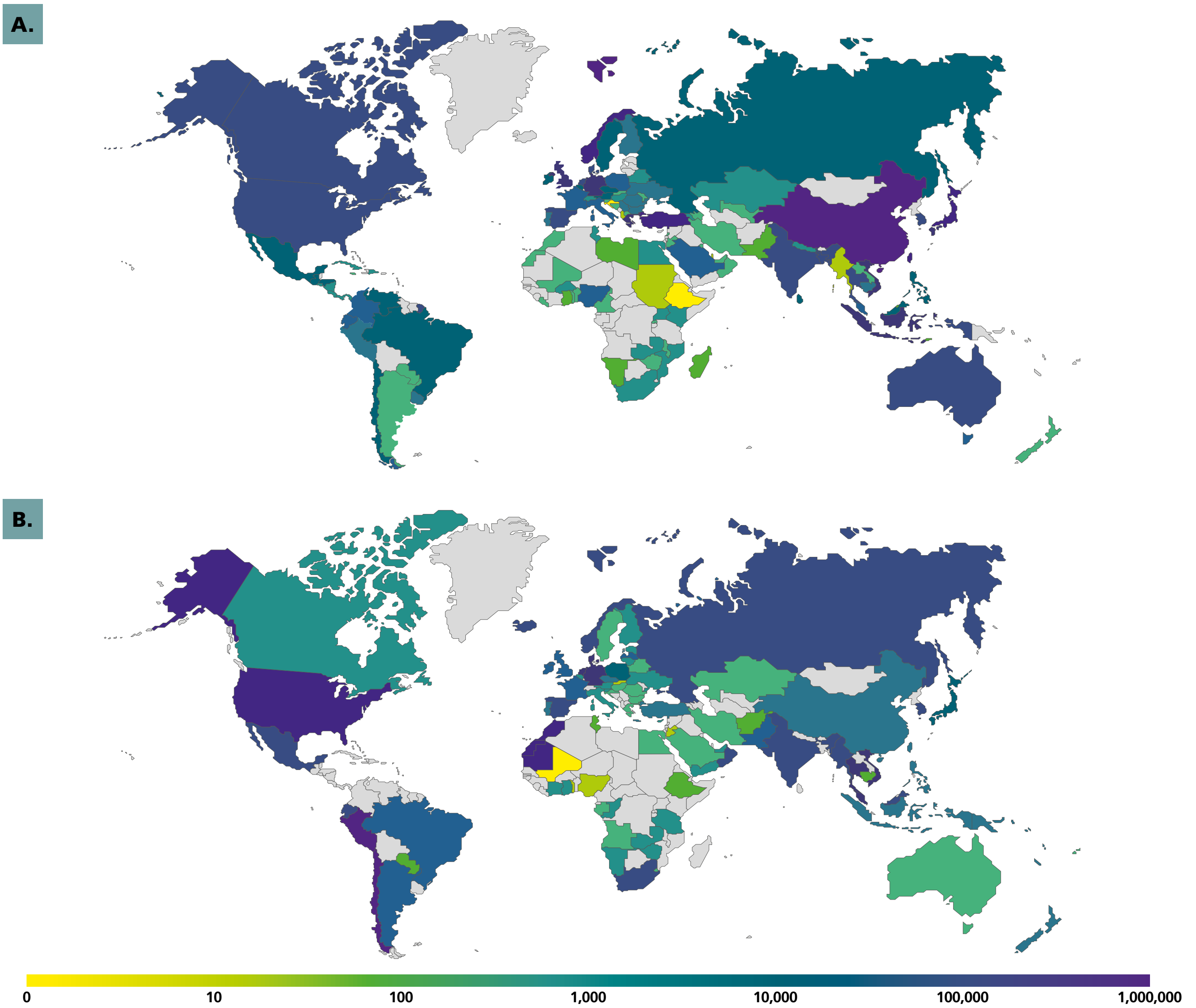

Figure 10. Global imports (A) and exports (B) of FMFO derived from wild capture fisheries in 2020. Data source: ARTIS dataset.

Europe's FMFO trade patterns broadly follow global trends, though imports have declined more steeply than exports (Annex Figure 26). In 2020, the top five importers in Europe were the United Kingdom (98,581 MT), Greece (84,414 MT), Germany (76,806 MT), Spain (51,244 MT), and Denmark (44,809 MT) (Figure 11A). These patterns in FMFO consumption largely track where aquaculture production is highest across Europe, including the United Kingdom's farmed salmon industry and Greece's farmed seabass/seabream industry (Figure 4B and Figure 6). Germany may appear partly as a major imports and processing hub, where FMFO is imported, processed, and then redistributed to aquafeed producers and users across Europe (36). Although sourcing patterns varied across Europe's top five importers, Denmark, Morocco, and Peru, consistently appeared as key sources of FMFO, mirroring their substantial reduction fisheries and status as major FMFO exporters (Figure 11B).

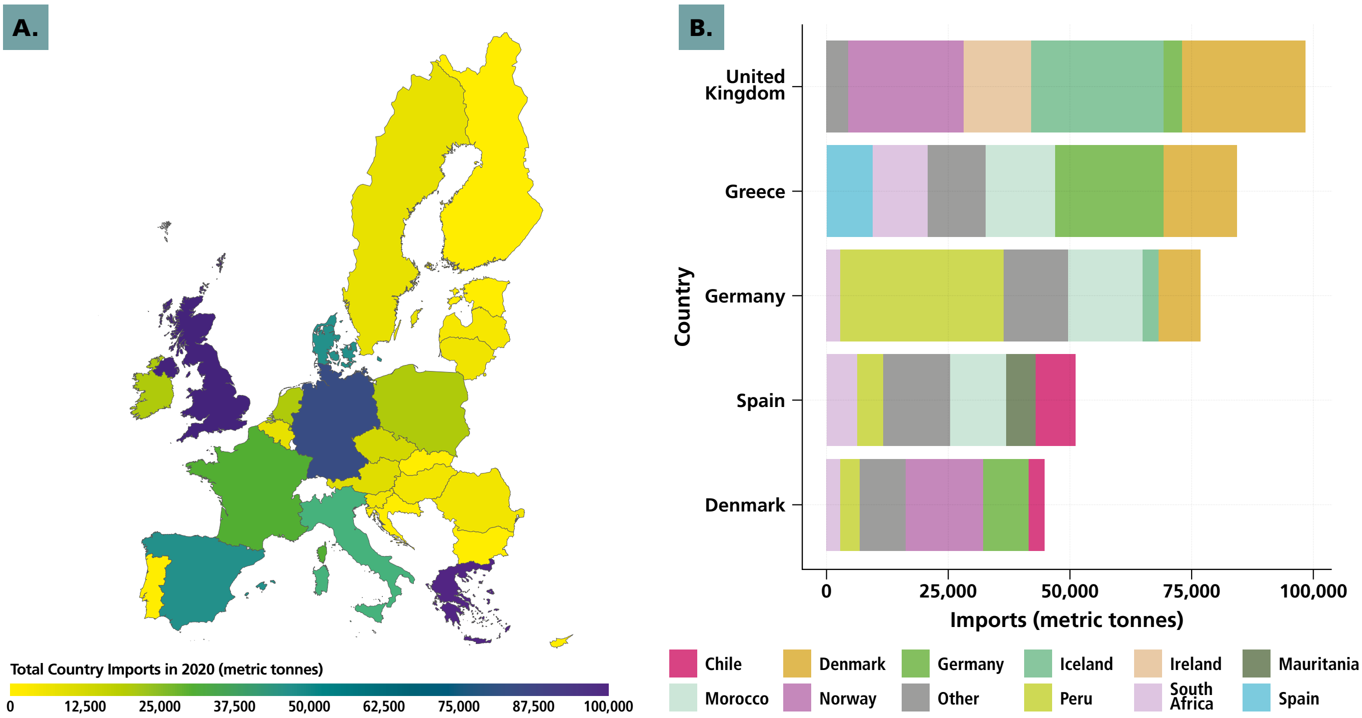

Figure 11. European imports of FMFO derived from wild-capture fisheries in 2020 - total FMFO imports per country (A) and source countries for the top five European importing countries (B). For each importer, only the top five source countries are distinguished; all remaining sources are grouped under "Other" in grey. Data source: ARTIS dataset.

In 2020 the top five exporters in Europe were Denmark (177,253 MT), Germany (75,000 MT), the Netherlands (43,841 MT), Spain (33,548 MT), and the United Kingdom (20,464 MT) (Figure 12A). While exporting practices of FMFO varies across these countries, there are some common destination countries, including to Greece and Norway (Figure 12B), two of the top aquaculture producers in Europe (Figure 4A and Figure 6).

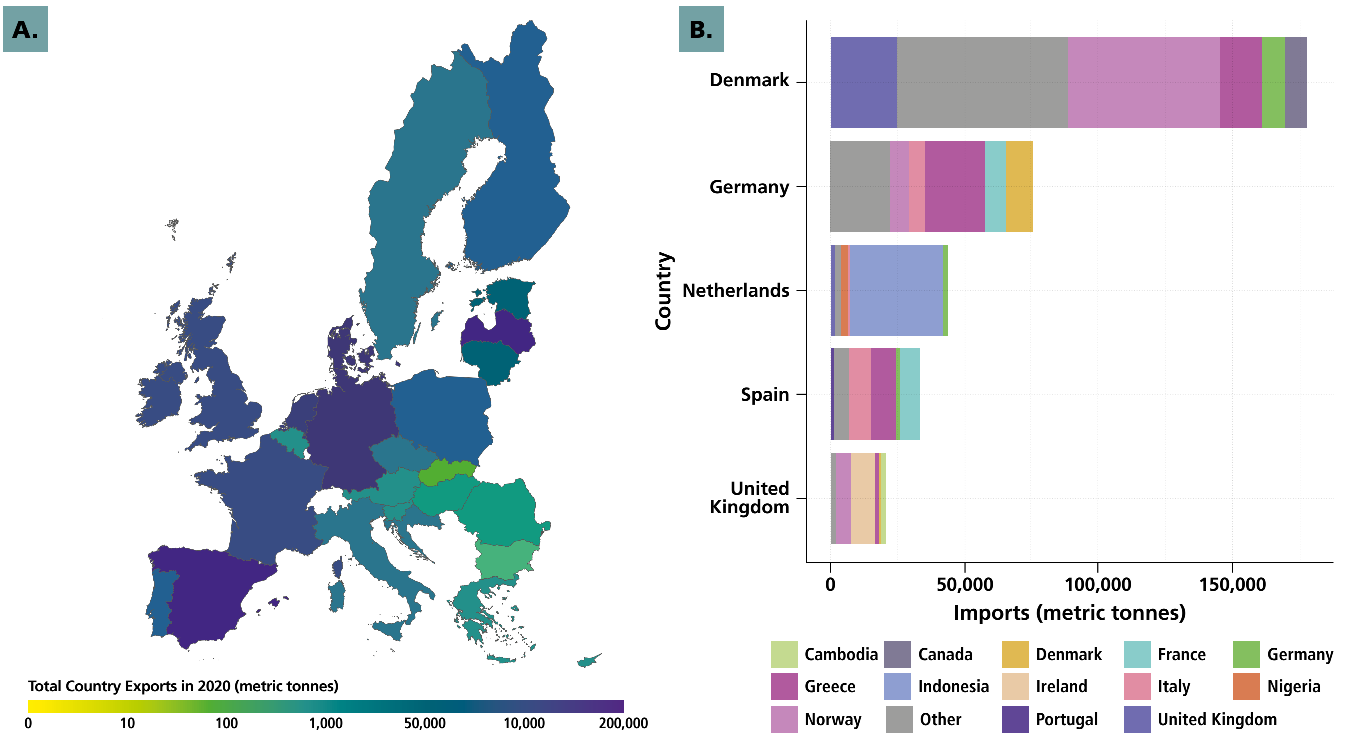

Figure 12. European exports of FMFO derived from wild-capture fisheries in 2020 - total FMFO exports across Europe (A) and destination countries for the top five European exporting countries (B). For each exporter, only the top five destination countries are distinguished; all remaining destination countries are grouped under "Other" (in grey). Data source: ARTIS dataset.

Expansion of existing carnivorous aquaculture in Europe

Carnivorous aquaculture remains the fastest growing aquaculture sector in Europe[7] (see Figure 7). Projections of production of the top ten carnivorous and omnivorous species with the highest annual output in Europe[8], suggest production may reach approximately 860,450 MT by 2040, representing a 30% increase from production in 2023. Among these ten species, Rainbow trout (208,498 MT), Atlantic salmon (207,080 MT), Gilthead seabream (144,928 MT), European seabass (144,167 MT), and Atlantic bluefin tuna (72,424 MT) have the highest predicted production by 2040 (Figure 13A, Figure 14A, and Annex Table 4). When projections of production of all ten species are calculated by country, the United Kingdom (202,836 MT), Greece (173,570 MT), Spain (99,304 MT), Italy (51,985 MT), and Croatia (48,870 MT) are expected to account for the highest levels of production (Figure 13B, Figure 14B, and Annex Table 5). See Methods for further details on analytical approaches used to derive projections.

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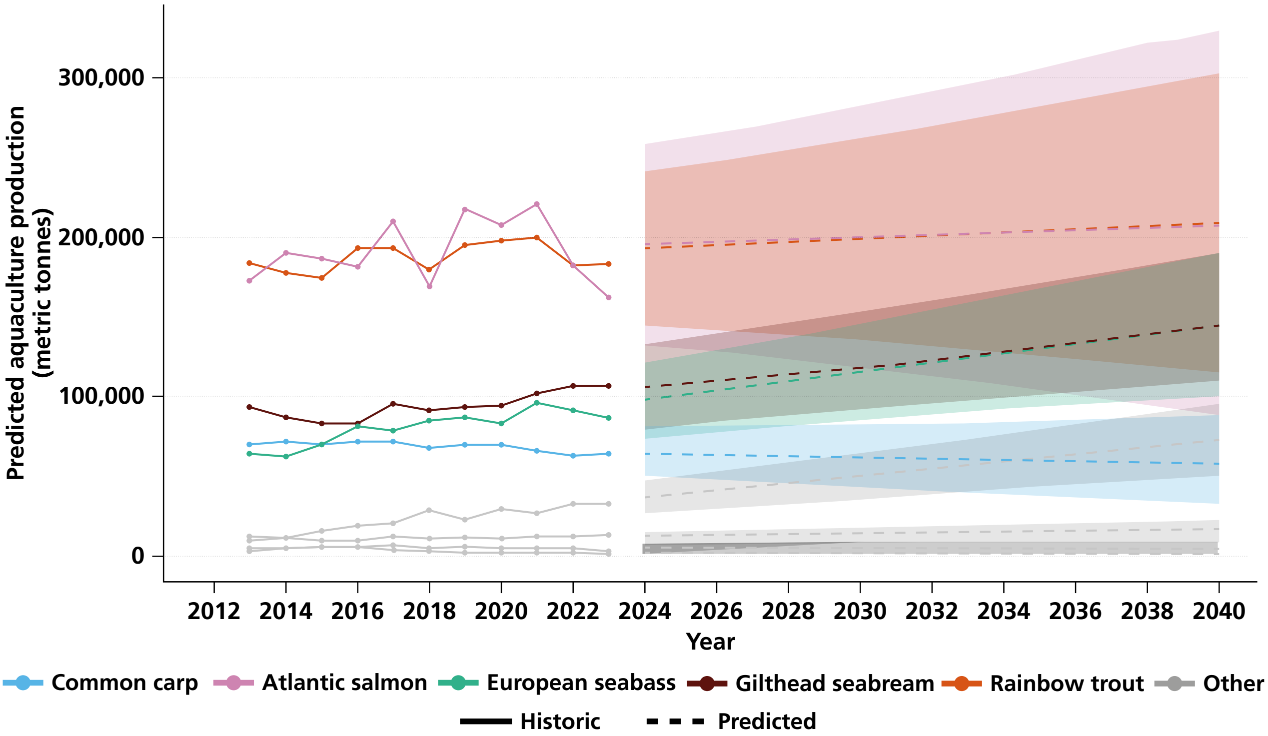
7 Europe includes EU Member States and the United Kingdom.
8 These species include all finfish listed in Figure 6 except for Goldfish.

A.



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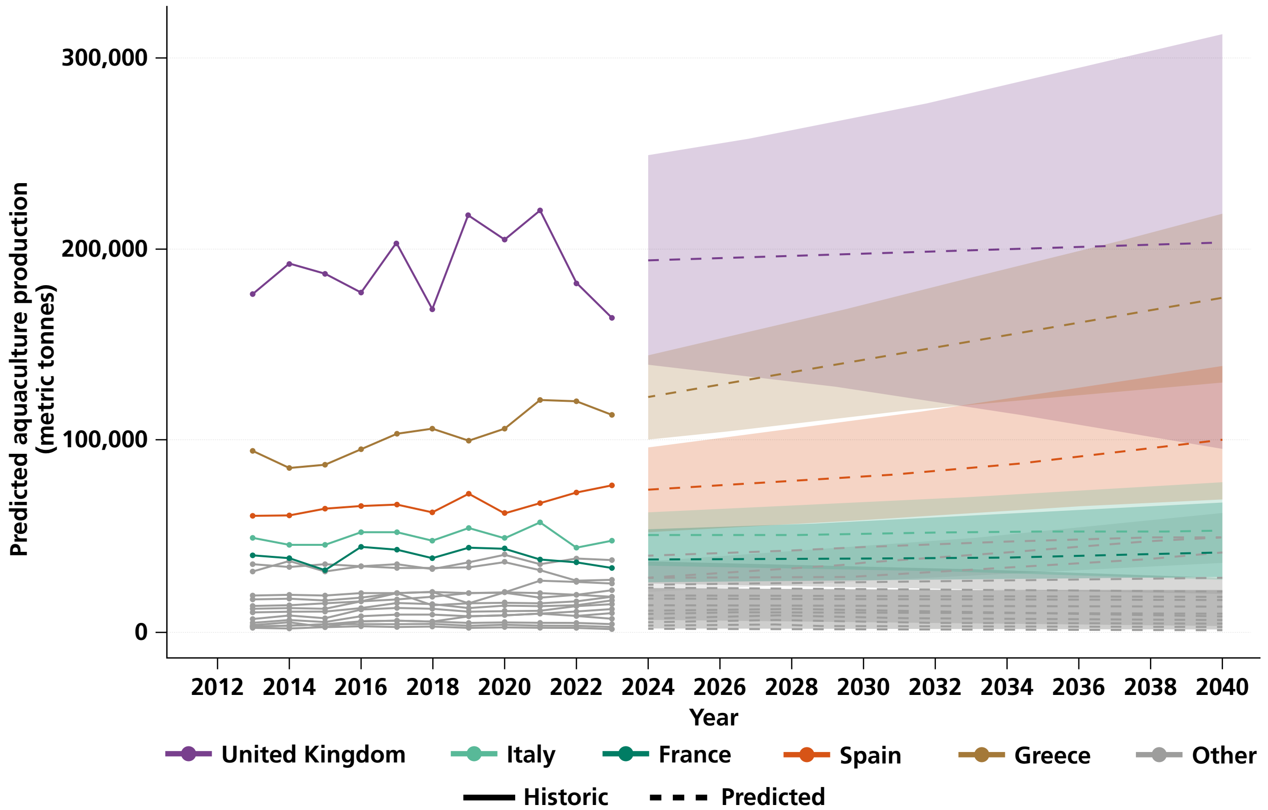
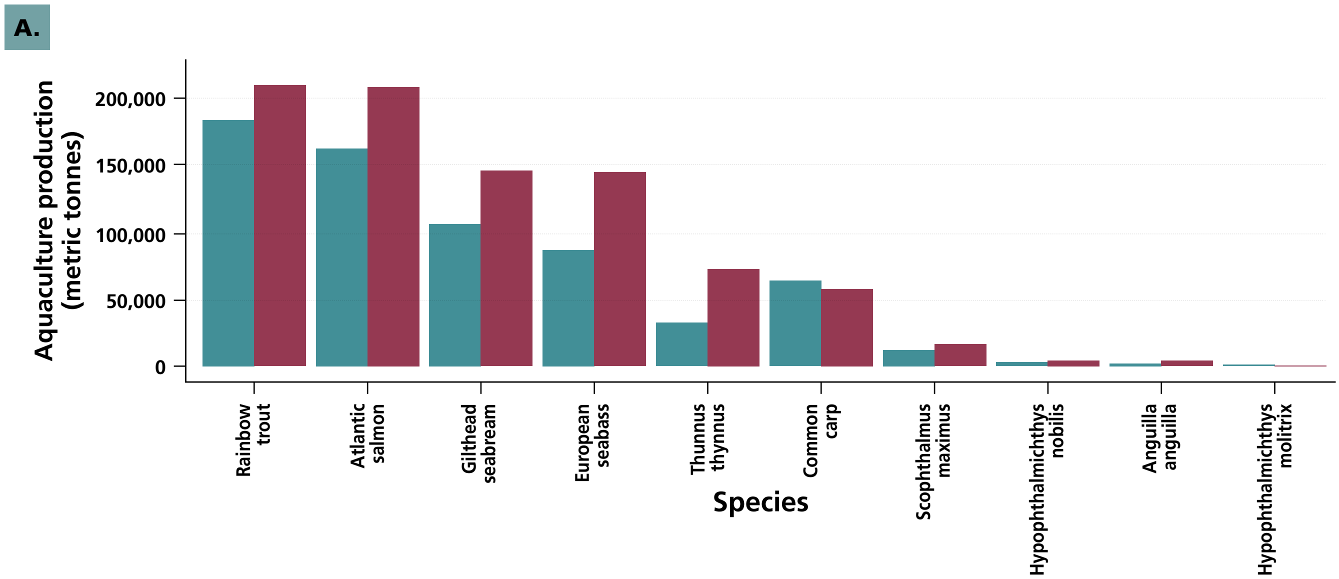


Figure 13. Projected aquaculture production between 2013 to 2040 of the ten carnivorous and omnivorous species with the highest mean annual production in Europe, by species (A) and by country (B). Solid lines represent historic production, and dashed lines represent projections. The shaded area corresponds to the approximate 95% prediction intervals for a given species or country. Only the top five species and countries are distinguished by colour. For further details see Methods and Annex Table 4 and Table 5.



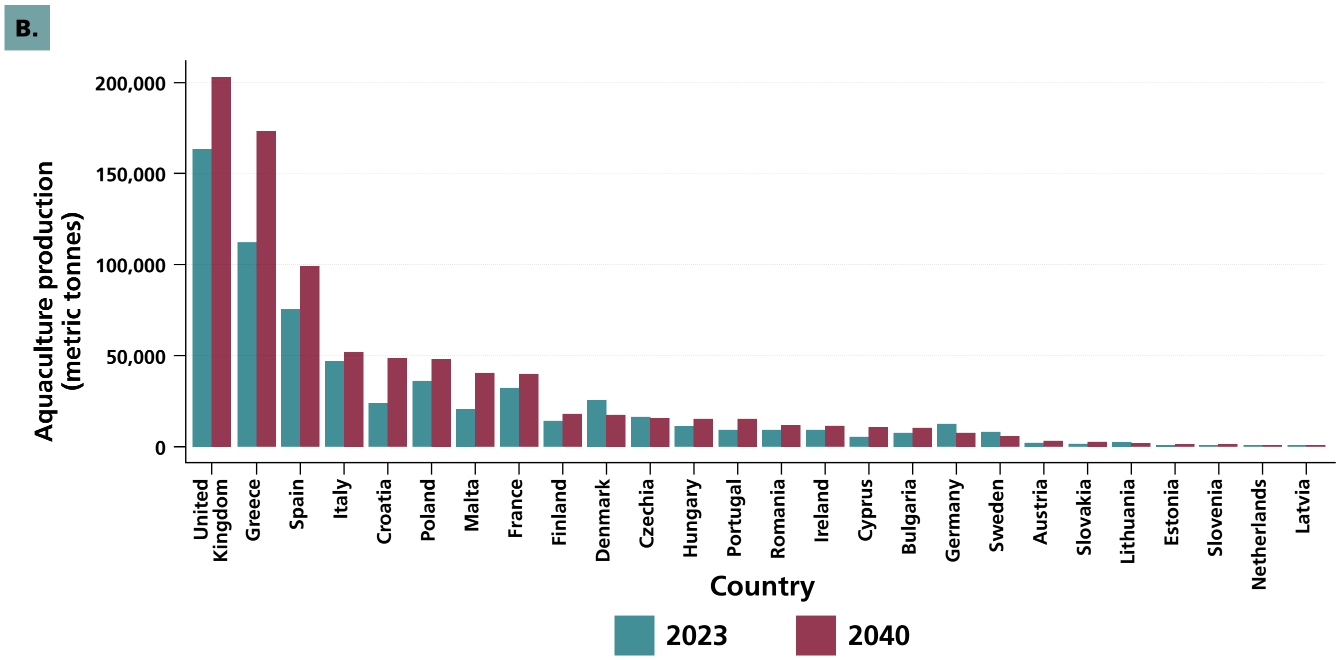


Figure 14. Historical (2023) and projected (2040) aquaculture production of carnivorous and omnivorous species with the highest mean annual output in Europe, shown by species (A) and country (B). For 2040, mean projected production values are displayed.

With these projections of aquaculture production, there is also an expected increase in FMFO use derived from wild-capture forage fish. Accounting for species-specific FCR and inclusion rates of fishmeal (FM) and fish oil (FO) from wild-capture forage fish in aquafeed (see Annex Table 7 and Methods), the use of forage fish for FMFO is expected to grow to 2.5 million MT by 2040, meaning 83.3 to 192 billion fish, representing a 70% increase relative to 2023[9]. Among the ten carnivorous and omnivorous species investigated, Atlantic Bluefin tuna (1.4 million MT), Atlantic Salmon (405,528 MT), Rainbow trout (208,797 MT), Gilthead seabream (179,711 MT), and European seabass (126,002 MT) have the highest projected use of forage fish in 2040 (Figure 15A, Figure 16B, and Annex Table 8). When the projected use of wild-capture forage fish by these species is calculated by country, Malta (777,406 MT) and Spain (631,424 MT) have the highest projected use of forage fish in FMFO in 2040 (Figure 15B, Figure 16B, and Annex Table 9).

9 Assuming the same current level of alternative protein inclusion in feeds.

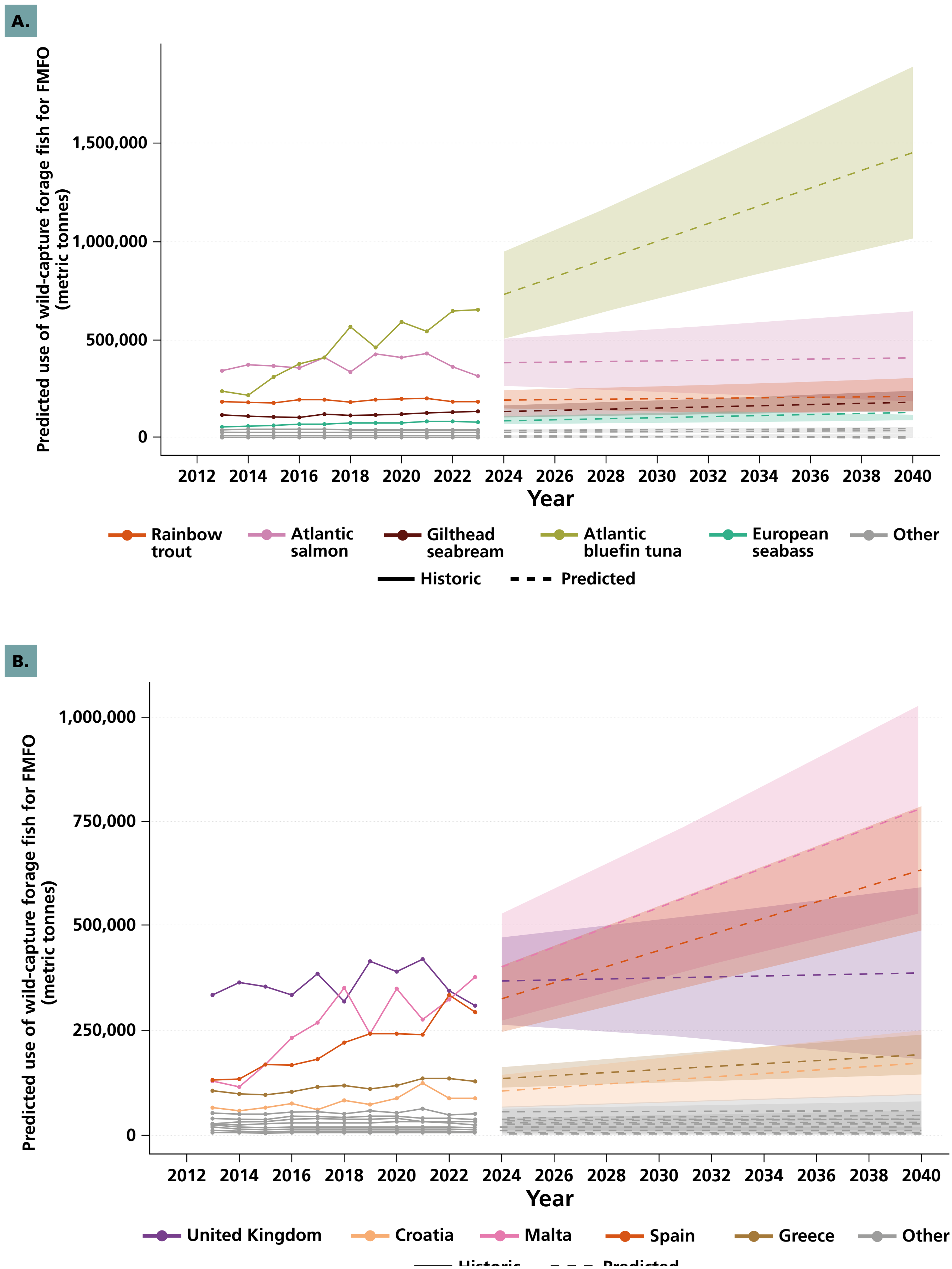


Figure 15. Historic and projected use of wild-capture forage fish from 2024 to 2040 for the ten carnivorous and omnivorous species with the highest mean annual production in Europe. Projections were aggregated by species (A) and by country (B). The solid lines represent historic use of forage fish for FMFO and the dashed lines represent projections for a given species or country. The shaded area corresponds to the 95% prediction intervals. Only the top five species and countries are distinguished by colour. For further details see Methods and Annex Table 8 and Table 9.

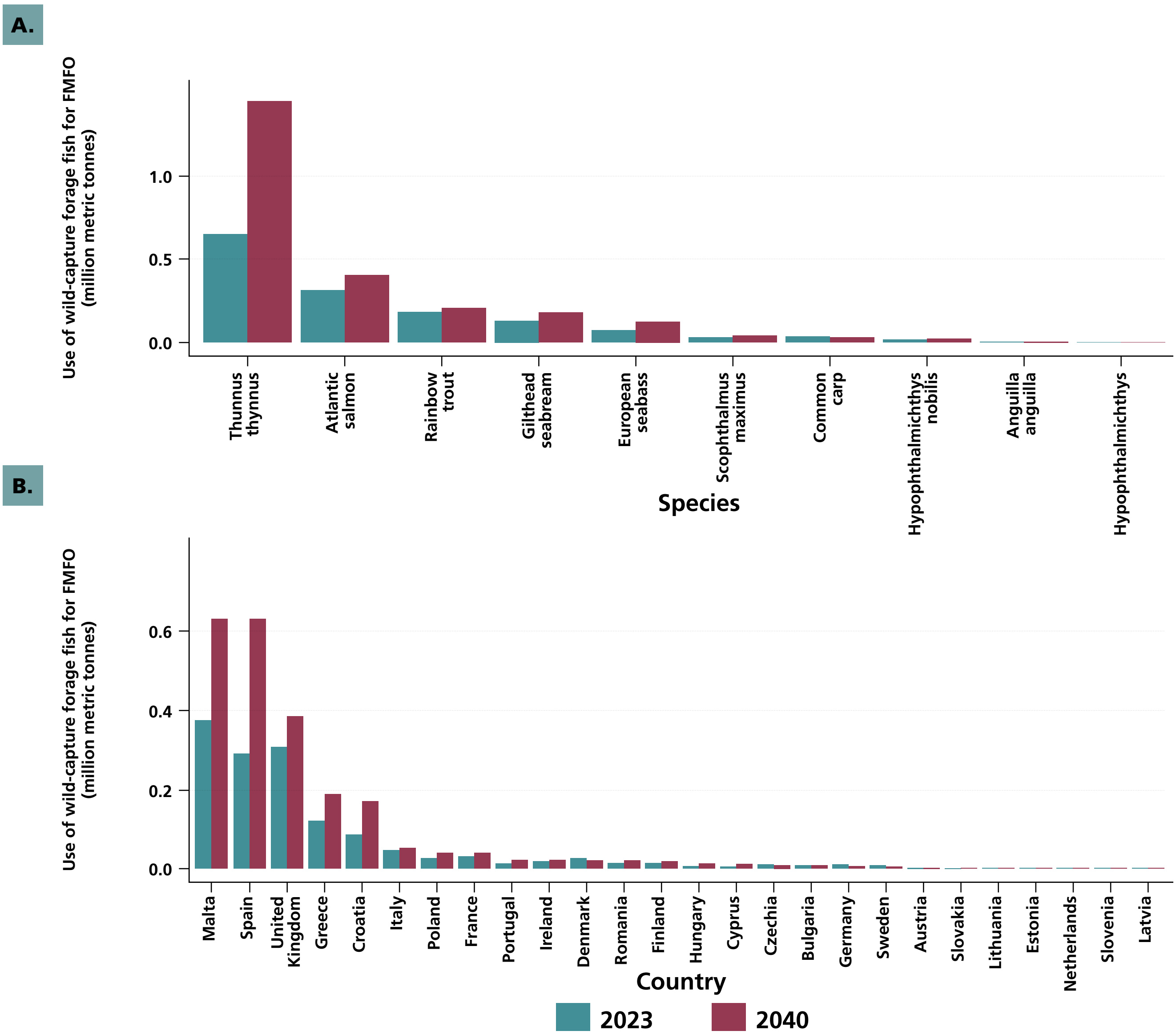


Figure 16. Historical (2023) and projected (2040) use of wild-capture forage fish for the ten carnivorous and omnivorous species with the highest mean annual production in Europe, shown by species (A) and country (B). For 2040, mean projected production values are displayed.

Expansion of new species in Europe

While there is concern regarding the expansion of Europe's[10] existing portfolio of carnivorous species, growing attention is also being placed on the farming of new carnivorous species. Since 1985[11], 78 new species[12] have been added to Europe's commercial scale aquaculture operations, of which around 70% rely on animal protein in their diets to varying degrees (29% carnivorous; 41% omnivorous (Figure 17)). Notable examples include Atlantic bluefin tuna ranching, where operations in the Mediterranean remains largely capture-based and reliant on wild-caught juveniles and vast amounts of forage fish is required for their diet, raising major sustainability and ethical concerns (37,38) and Atlantic cod, which has received commercial interest but remains constrained by high production costs, larval rearing challenges, and recurrent boom-and-bust cycles (39,40). The push to expand farming of such carnivorous species is largely driven by market demand for premium, high-value seafood, alongside government and industry ambitions to diversify aquaculture production and reduce reliance on declining wild fisheries (4). However, the introduction of new carnivorous species into aquaculture portfolios raises concern over future dependencies on FMFO sourced from wild-capture fisheries, intensifying pressures on forage stocks, and the erosion of marine ecosystem resilience if demand continues to grow. Taken together, the expected rise in carnivorous aquaculture production and associated FMFO use, risks locking the sector into escalating reliance on finite marine resources, thereby undermining both fisheries sustainability and broader marine ecosystem resilience.

Introduction of new species since 1985

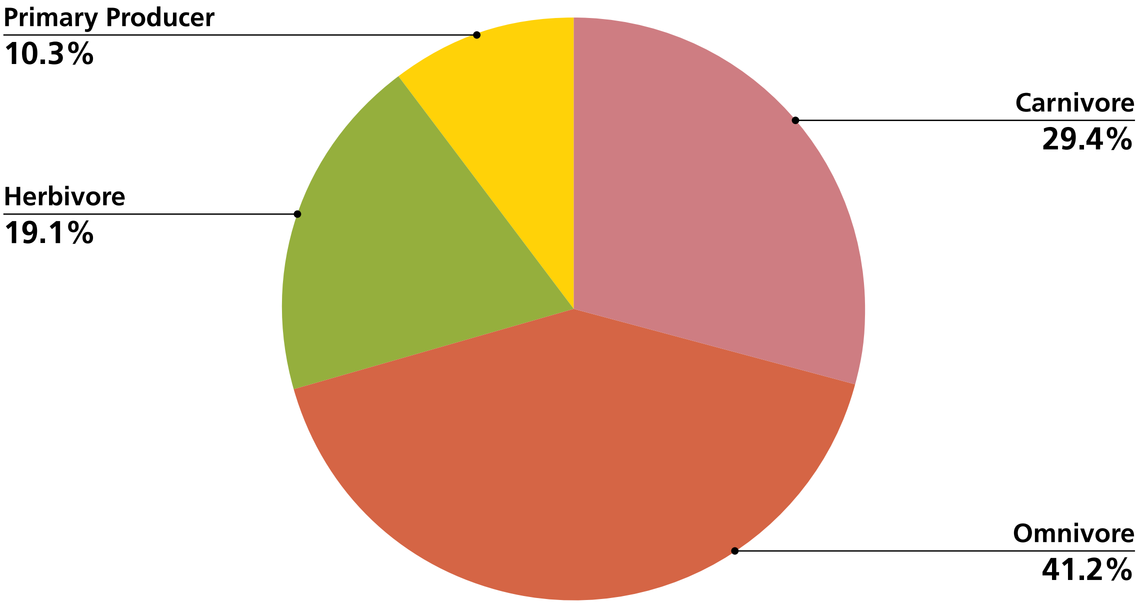


Figure 17. Breakdown of newly introduced aquaculture species in Europe from 1985 to 2023 by trophic group. For further details see Methods and Annex Table 10. Data source: FAO FishStatJ – Global Aquaculture Production dataset.

10 Europe includes EU Member States and the United Kingdom.
11 1985 is used as the baseline year, as FAO aquaculture statistics from this point onward provide more consistent identification of newly introduced species (6).
12 Only includes new species that have at least seven years of production data in Europe since 1985.

Spain's growing dependence on unsustainable feed sources and aquaculture species

A closer look at Spain's FMFO sourcing

Spanish imports of FMFO from wild-capture fish have fluctuated considerably over time (Figure 18A-C). Volumes peaked in 2000 at 111,912 MT, declined to a low of 27,878 MT in 2013, and subsequently recovered to 51,244 MT by 2020. Sourcing patterns have also shifted over time. Until approximately 2012, Spain obtained the majority of its FMFO from Peru, Denmark, and Chile. Thereafter, imports from Peru decreased sharply. The decline in Spain's FMFO imports after 2012 can be attributed primarily to reduced supply from Peru, driven by both ecological variability in anchoveta (*Engraulis ringens*), and regulatory measures introduced to stabilise stocks and prioritise domestic use within Peru (32). During this period of reduced supply of FMFO from Peru, Spain diversified its sourcing of FMFO, with increased sourcing from other countries, including Mauritania and South Africa. In Mauritania, sardinella are increasingly reduced into FMFO despite signs of overexploitation (41), while in South Africa, sardine (*Sardinops sagax*) collapsed in the past due to overfishing and remain volatile, making their use in FMFO reduction fisheries a continued concern (42).

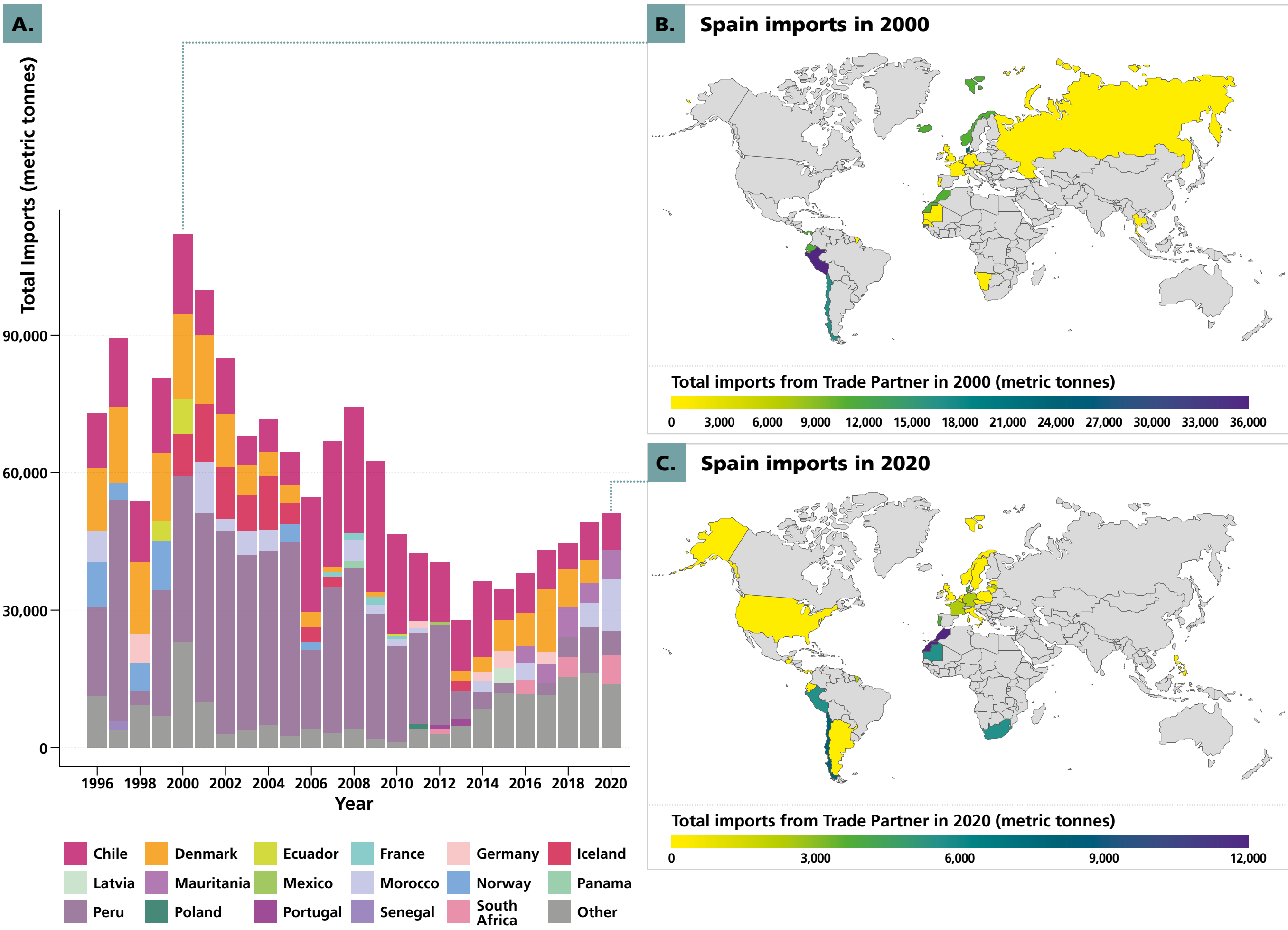


Figure 18. Spain imports of FMFO derived from wild-capture fisheries. Through time (A). Spain's imports of FMFO in 2000 (B) and 2020 (C) are visualised spatially on a map. Data source: ARTIS dataset.

The ecological and social footprint of Spain's FMFO use is shaped not only by its use within Spain and the associated impacts of Spanish aquaculture operations, but also by the impacts of forage fish fisheries within the countries supplying the FMFO. Therefore, understanding where Spain sources its FMFO, particularly that derived from wild-capture fisheries is important, as the practices of source countries strongly shape wider impacts. Depending on the status of local fisheries in source countries, their fisheries management and trade governance frameworks, and the reliance of their coastal communities on forage fish for food security and livelihoods, imports of FMFO from certain countries can exacerbate overfishing, undermine local nutrition, and increase social vulnerability.

In 2020, Spain sourced FMFO from 26 countries[13], the largest network of source countries among all European countries (Figure 19). Assessing the FMFO source of Spain imports from countries against indicators of IUU fishing risk, dependence on fish for protein, sustainable fisheries management, and compliance with RFMO port obligations, presents a mixed picture of potential ecological and social impacts (Figure 20 and Annex Figure 28)[14]. Spain's sourcing practices in 2020 were characterised by:

- imports from countries with relatively high IUU fishing risk (7th highest in Europe)
- the worst performance on sustainable fishing practices (MSC-certified fisheries) (1st in Europe)
- countries with low reliance on fish for dietary protein (23rd in Europe)
- high compliance with RFMO port obligations (23rd in Europe) relative to other European importers.

Spain's dependence on countries with limited sustainable fishing practices and elevated risks of IUU fishing, highlights how current sourcing practices may intensify both ecological pressures on foreign forage fisheries and exacerbate associated social risks in FMFO source countries. For example, stock assessments indicate that Mauritania's and Morocco's sardinella fisheries are severely overexploited, with Round sardinella (*Sardinella aurita*) biomass reduced to ~5% of unexploited levels and Flat sardinella (*S. maderensis*) to ~18% (41). These pressures are compounded by unauthorised fishing by foreign vessels, resulting in under-reported catches that distort landing statistics and obscure the true extent of overfishing (43). At the same time, sourcing from countries with low domestic reliance on fish for protein reduces immediate competition with local food security needs, and sourcing from countries with relatively high compliance with RFMO port obligations provides a foundation to strengthen traceability and oversight. These strengths demonstrate that, while risks remain significant, there are positive elements Spain can build upon to move toward more responsible and sustainable sourcing of FMFO.

13 Spain imported FMFO from 27 countries, 26 of which had IUU Fishing Risk Index scores.
14 A comparison of all European countries' FMFO sourcing in 2020 across the four indicators is provided in Annex Figure 28.

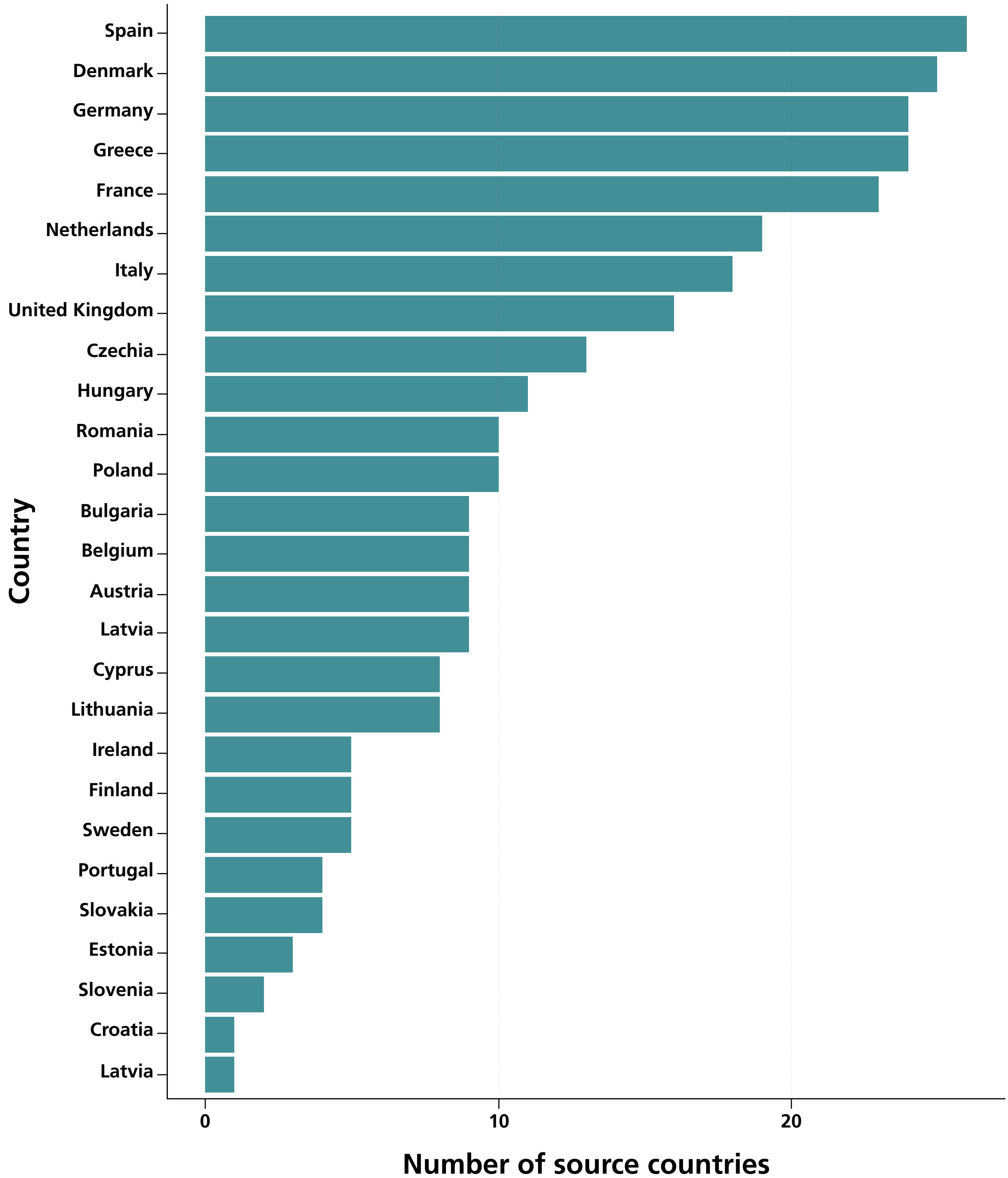


Figure 19. Number of source countries imported from in 2020 by European country, ordered in descending order. Only source countries with available IUU fishing risk scores were included in the analysis. Data sources: ARTIS dataset and IUU Fishing Risk Index.

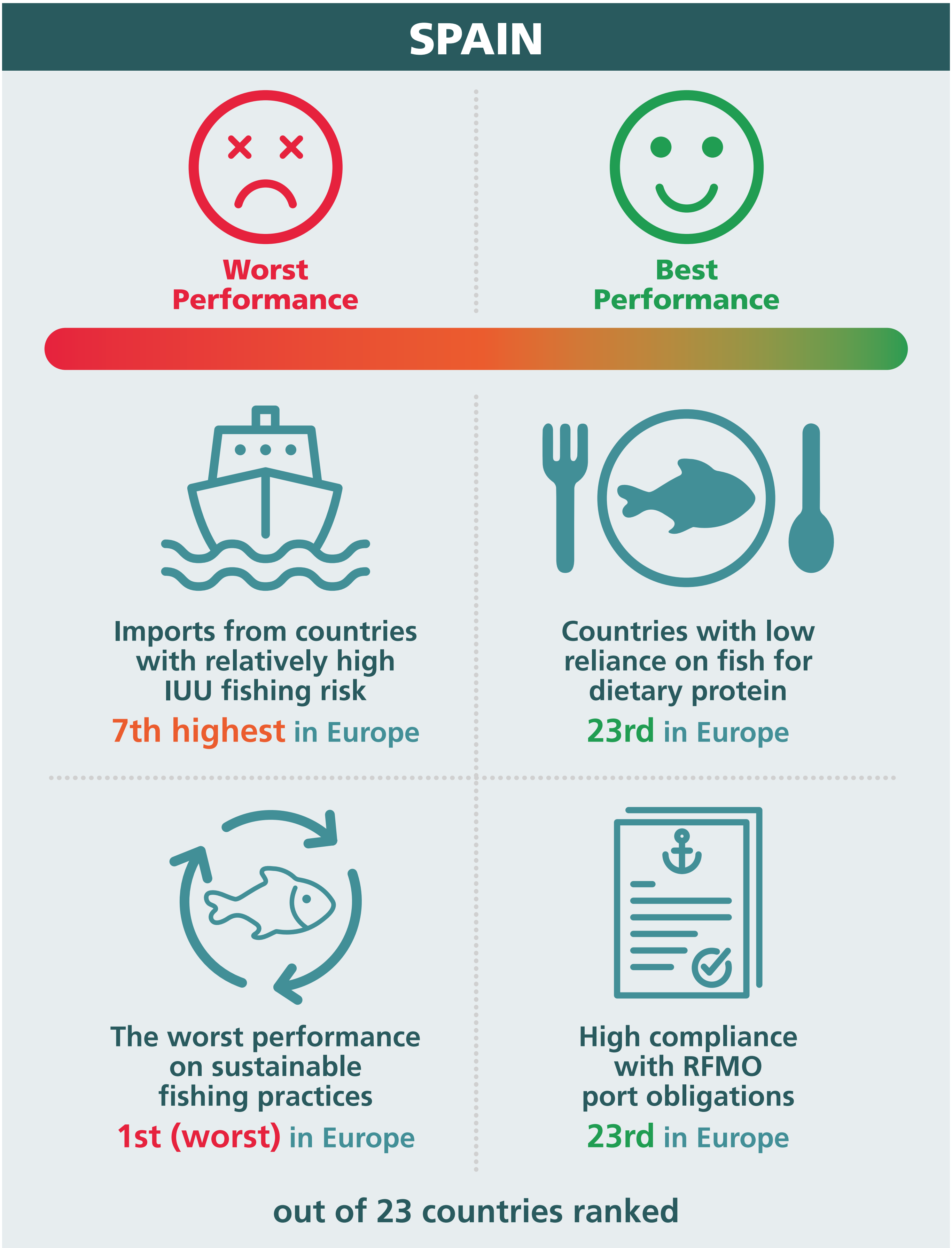


Figure 20. Ecological and social impact of Spain's sourcing practices of FMFO derived from wild-capture fisheries in 2020, assessed across four indicators: overall IUU fishing risk (A), prevalence of MSC-certified fisheries (as a proxy for market attitude towards sustainable fishing practices) (B), dependence on fish for protein (C), and compliance with RFMO port obligations (D). For further details on how these weighted scores are derived for Spain, see Methods. For Spain's and the other European countries' performance for each indicator and source country see Annex Figure 27 and Figure 28.

Octopus farming in Spain

Growing demand and rising prices for wild-caught octopus have placed an increasing strain on wild populations (44). In response, the seafood industry is seeking to develop commercial scale octopus farming. To date, Spain has led these efforts to industrialise octopus farming and in 2021, Nueva Pescanova announced plans to build the world's first commercial octopus farm in the Canary Islands, Spain (45). This project sparked international controversy, with growing concerns about its implications for animal welfare, environmental sustainability, and food security (46).

Octopuses are highly intelligent, sentient, and solitary animals, capable of problem-solving, tool use, and complex behaviours (47). Given their cognitive sophistication and naturally solitary lifestyles, rearing octopuses in crowded tanks poses a significant threat to their welfare, including risks of injury, aggression, and cannibalism (48). With no established welfare legislation for cephalopods in aquaculture, major gaps in protections around rearing, handling, and slaughter of octopuses remain a significant concern (44, 46).

Nueva Pescanova expects an annual output of 3,000 tonnes once the farm reaches full production capacity, which equates one million individual octopuses (45,49). If octopus farming follows a similar linear growth trajectory observed by other carnivorous species introduced in Europe since 1985 (Annex Figure 28), octopus aquaculture production could reach 9,713 tonnes (90% quantile range: 3,008-21,731), equating to 3.2 million octopuses by 2040 (Figure 21, Table 1), more than triple the initial expected annual output.

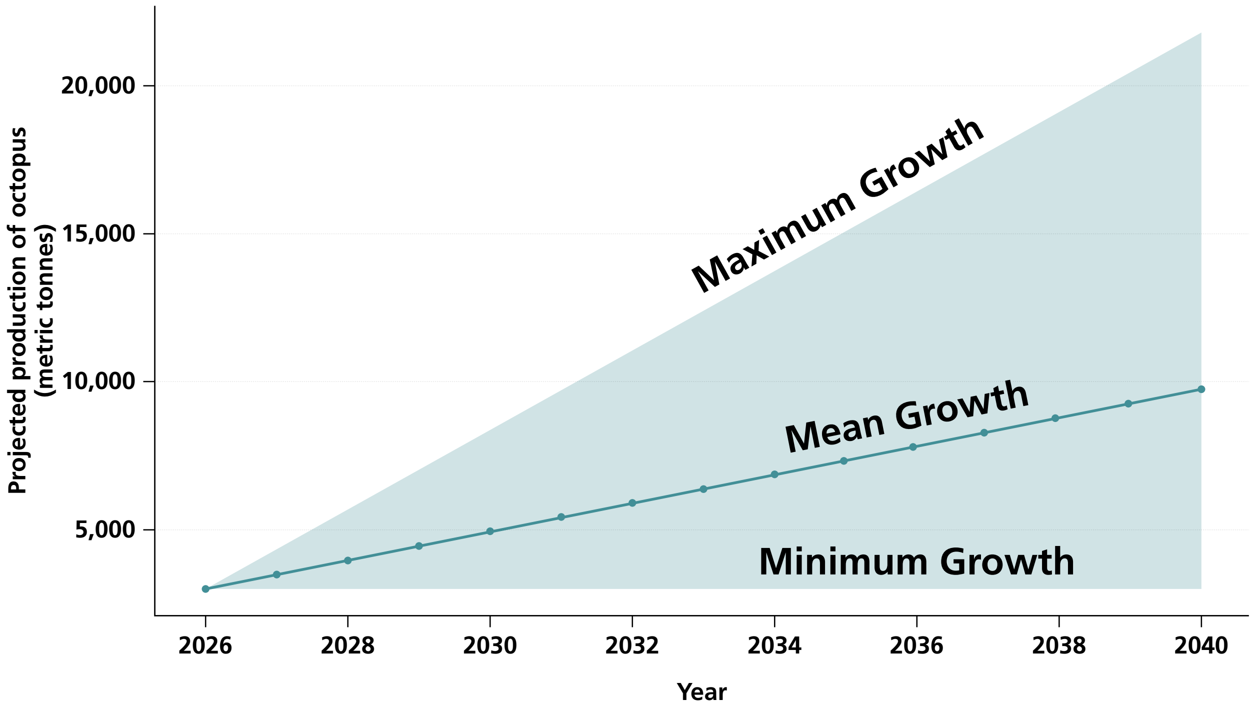


Figure 21. Projected octopus aquaculture production from 2026 to 2040 assuming a similar linear growth modelled from carnivorous species introduced in Europe since 1985. The solid line indicates mean projections, while the shaded area represents the 90% quantile range. For further details see Methods.

Given that octopuses are carnivorous species with high protein demands, their dependency on fish protein poses a significant sustainability concern (46). Reported FCRs for octopus vary, with scientific literature suggesting averages around 3:1(44), while industry proponents such as Nueva Pescanova claim they can achieve FCRs closer to 2:1 (50). Using projected octopus aquaculture production from 2026 to 2040 (Figure 21, Table 1), these FCR values, and two scenarios of FM inclusion rates[15], octopus farming is expected to use on average 17,000 and 90,000 MT of wild-capture forage fish in 2040, meaning 0.6 to 7.0 billion fish, more than triple that which is expected in 2026 (Figure 22, Table 1).

Table 1. Projections of octopus aquaculture production of Nueva Pescanova and wild-capture forage fish use under varying FCR and inclusion rates. Mean projections (in MT) are provided for 2026 and 2040. 90% quantile ranges are presents in parentheses. For further details see Methods.

Feed Conversion Ratio	Inclusion rates of FM from wild-capture forage fish	Projected mean quantity of octopus aquaculture production (MT)		Projected mean quantity of wild-capture forage fish (MT)	
		2026	2040	2026	2040
2	20%	3,000	9,713 (3,008-21,731)	5,333	17,268 (5,348-38,633)
	70%			18,667	60,438 (18,717-135,217)
3	20%			8,000	25,902 (8,021-57,950)
	70%			28,000	90,657 (28,075-202,825)

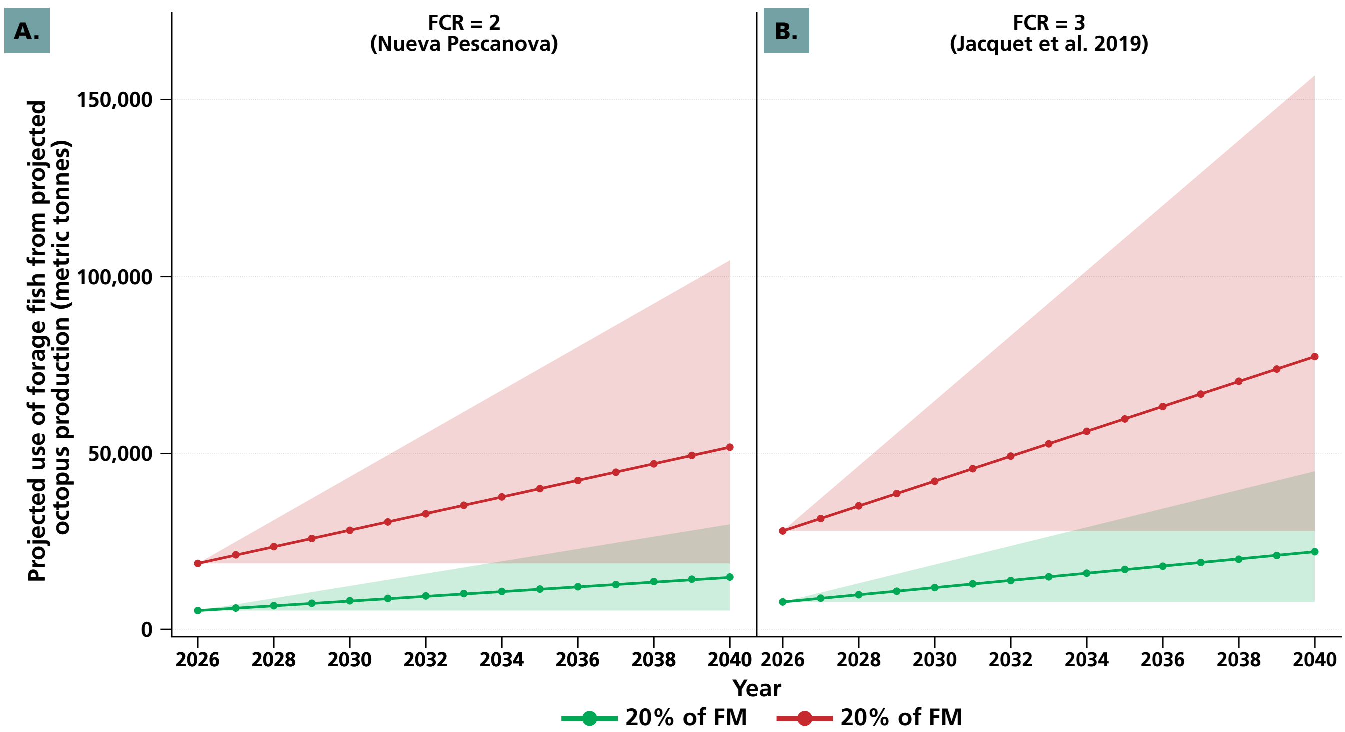


Figure 22. Projected forage fish use of projected octopus aquaculture production from 2026 to 2040 under different feed assumptions. Panel A assumes an FCR of 2, and the panel B assumes an FCR of 3. Projections are shown for diets containing 20% (in green) and 70% (in red) inclusion of FM derived from wild-capture forage fish based on previous studies. Solid lines indicate mean projections, while shaded areas represent 90% quantile range of mean projections. For further details on methods used to derive these projects, see Methods.

15 20% (reflecting a lower bound derived from dietary protein studies (51)) and 70% (reflecting historically high levels seen in the early development of carnivorous aquaculture feeds (30,31))

The high levels of wild-capture forage fish needed for octopus aquaculture will place additional strain on already overexploited stocks, exacerbate overfishing and weaken the resilience of marine ecosystems in countries supplying FMFO. This use of forage fish may also exacerbate global food security issues, particularly if sourced from regions such as West Africa, Southeast Asia, and South America – regions where forage fish fisheries are concentrated, from which Spain has previously sourced much of its FMFO (Figure 18), and where such fish are critical for local nutrition and livelihoods (7,46). In this context, the development of octopus farming represents not only animal welfare and ethical concerns, but also a major threat to fisheries and ecosystem sustainability, and food security (7,17,46).

The likely impacts of octopus farming – if it goes ahead - have begun to shape new regulatory and political responses worldwide. In Spain, the Canary Islands Government deemed Nueva Pescanova's environmental impact assessment (EIA) insufficient in 2023, determining that the project could cause "significant" adverse effects, noting it required a full review under the EU EIA Directive (52). As of June 2025, the project is still under environmental review and it still requires approval from the Canary Islands government. Meanwhile, the Spanish Parliament is set to debate a bill that would ban octopus farming and its commercialisation entirely (53). If the bill is passed, the outcome of the EIA for Nueva Pescanova's proposed octopus farm will be irrelevant because octopus farming would be banned outright. Resistance against octopus farming is also strengthening globally. Two US states – California (54) and Washington (55) – have enacted bans on the practice of octopus farming. California's law also prohibits the sale of farmed octopus and octopus meat in the state. At the federal level, the OCTOPUS Act (56) has been introduced to bar commercial octopus aquaculture nationwide and to prohibit the import of farmed octopus meat from future farms abroad, such as Nueva Pescanova. These efforts reflect growing recognition of the risks associated with farming octopus, and highlight the opportunity for Europe to establish a consistent and coordinated position on farming octopus.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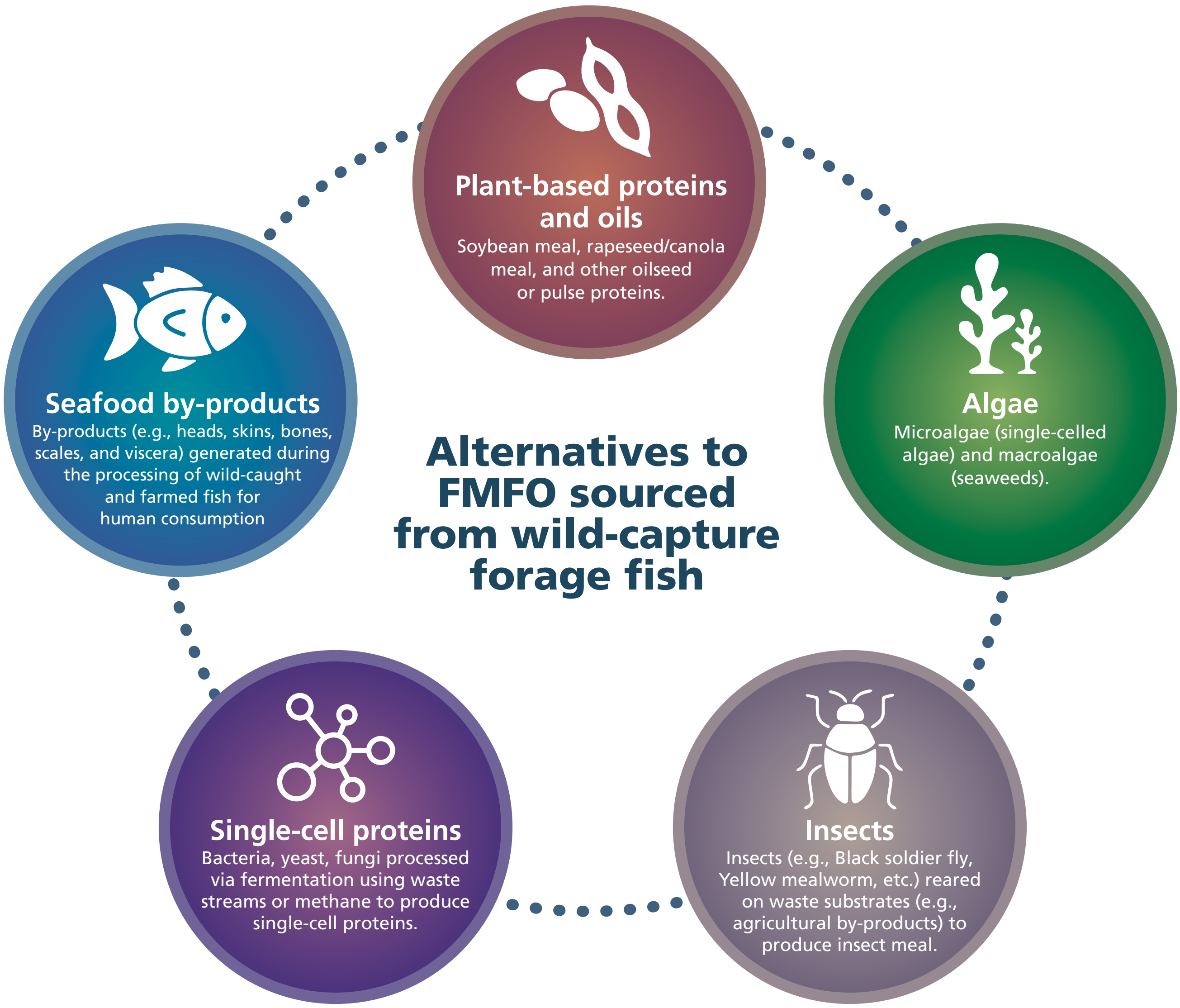
What are the alternatives to FMFO?

Growing concerns over the environmental and food security implications of FMFO produced using wild-caught forage fish, have prompted the aquaculture sector to explore ways to reduce reliance on these inputs (4,57). Strategies to reduce the use of FMFO include improving FCRs (producing more growth in cultured species with less feed[16]), only using FMFO for life stages where it provides the greatest benefit, and lowering inclusion rates of FMFO. The use of seafood by-products is an important contributor in the drive to reduce FMFO from whole-fish, and an attractive proposition from a business perspective – extracting additional revenue from waste streams in the seafood sector (4,57). Additional alternatives are also available and include algal meals and oils, plant-based proteins, single-cell proteins, and insect meals (58). However, not all alternatives are equal.



16 This often involves achieving greater growth per unit of feed through genetic improvement, optimized diets, and husbandry practices

By-products

A growing share of FMFO is now produced from seafood by-products generated during the processing of wild-caught and farmed fish. These by-products, such as heads, skins, bones, scales, and viscera, can account for between 30% and 70% of a fish's weight, depending on species and processing methods (59). The increasing use of by-products in FMFO (Figure 23) has helped maintain global FMFO production at roughly 5 million tonnes of FM and 1 million tonnes of FO annually since the mid 2000s, despite a decline in the share of FMFO sourced from wild-capture forage fish (4). However, a large proportion of FM (66%) and FO (47%) still originate from wild-capture forage fish (4). Globally, this waste stream is substantial. The World Economic Forum (WEF) estimated that nearly 15% of all aquatic food produced in 2021 was lost or wasted, highlighting both the scale of underutilisation and the opportunity for use of by-product to replace FMFO sourced from wild-capture forage fish (60).

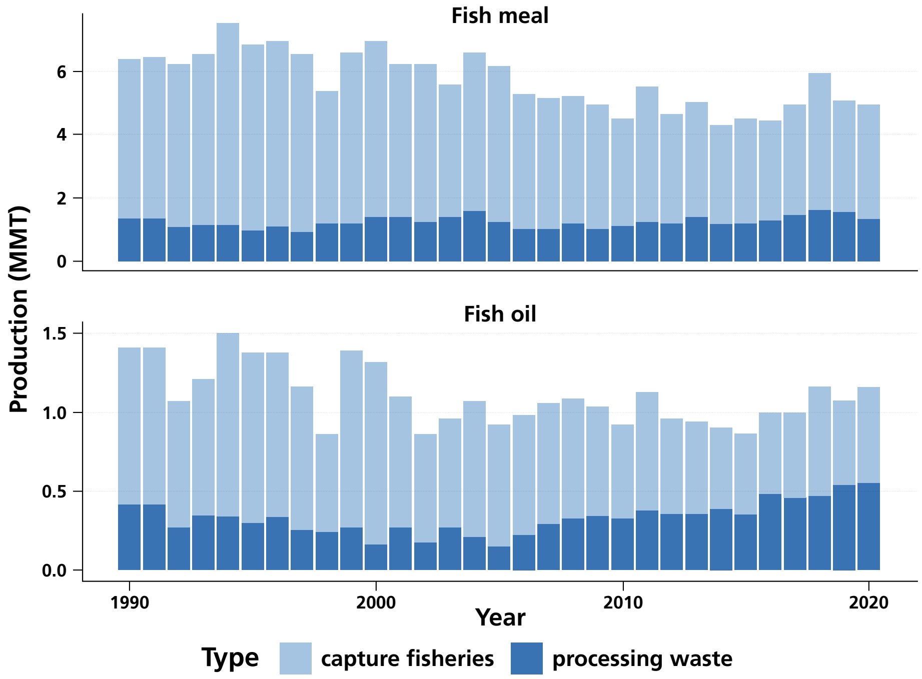


Figure 23. Global fish meal and fish oil production from 1990 to 2020 (million MT) (6)

Whilst the use of seafood by-products to replace FMFO from wild-capture fish continues to show promise, FM derived from by-products has a different nutritional profile compared to FM from whole fish – often lower in protein but richer in minerals (4)[17]. Since protein is critical for optimal growth and feed efficiency in aquaculture species (62), feeds containing higher proportions of seafood by-products, and therefore lower overall protein levels, must be carefully formulated to ensure animal welfare, sufficient performance, growth rates, and production levels can be achieved using alternative FMFO sources.

While seafood by-products are a valuable source of raw material for FMFO production, their wider use in aquafeeds is also constrained in some regions by logistical limitations and access to facilities that can process seafood waste products into meal and oil (57). Large, industrialised sectors (e.g., large-scale wild capture fisheries and aquaculture processing in the United States, Norway, and Vietnam) achieve high utilisation of by-products because steady volumes justify investment in the infrastructure needed to process such inputs. In contrast, smaller-scale, highly seasonal, or remote wild capture operations often face dispersed supply, limited storage and preservation options; and long transport distances to processing plants, making by-product conversion less viable (57). In face of these challenges, utilisation of by-products is expected to grow further as processing infrastructure and value-chain efficiencies expand, positioning by-products as a critical pathway to ease dependence on FMFO sourced from wild-capture forage fish (63).

17 Although this can vary depending on the species (61) and parts (59) used.

Plant-based proteins and oils

Plant-derived ingredients remain the dominant non-marine alternative to FMFO in aquafeeds (Figure 24), largely because they are widely available, relatively inexpensive, and supported by established supply chains (4,58). Inclusion of plant-based proteins and oils, such as soybean meal, rapeseed/canola meal, and other oilseed or pulse proteins into aquafeed can significantly reduce the use of FMFO derived from wild-capture fisheries. In fact, in Norwegian salmon aquaculture, plant-derived proteins and oils make up more than 70% of the feed formulation (64). However, the long-term reliance on these inputs raises concerns over changes in land use and biodiversity loss (65). For example, soybean meal, which is affordable and widely used in aquafeed production, relies on large-scale monocultures of soy which have been linked to deforestation and water pollution driven by the intensive agricultural practices used to produce the soy (33). This also has documented negative consequences for ecosystems and the wellbeing of local communities in soy-producing regions (66). In addition, soy is a staple source of protein for direct human consumption, meaning that its diversion into aquafeeds can also raise concerns for food security (67). Beyond environmental concerns, plant proteins and oils also differ nutritionally from FMFO in protein content and amino acid profile, making it an animal welfare issue and requires a combination with other, often marine, ingredients to meet the full nutrient requirements of aquaculture species.

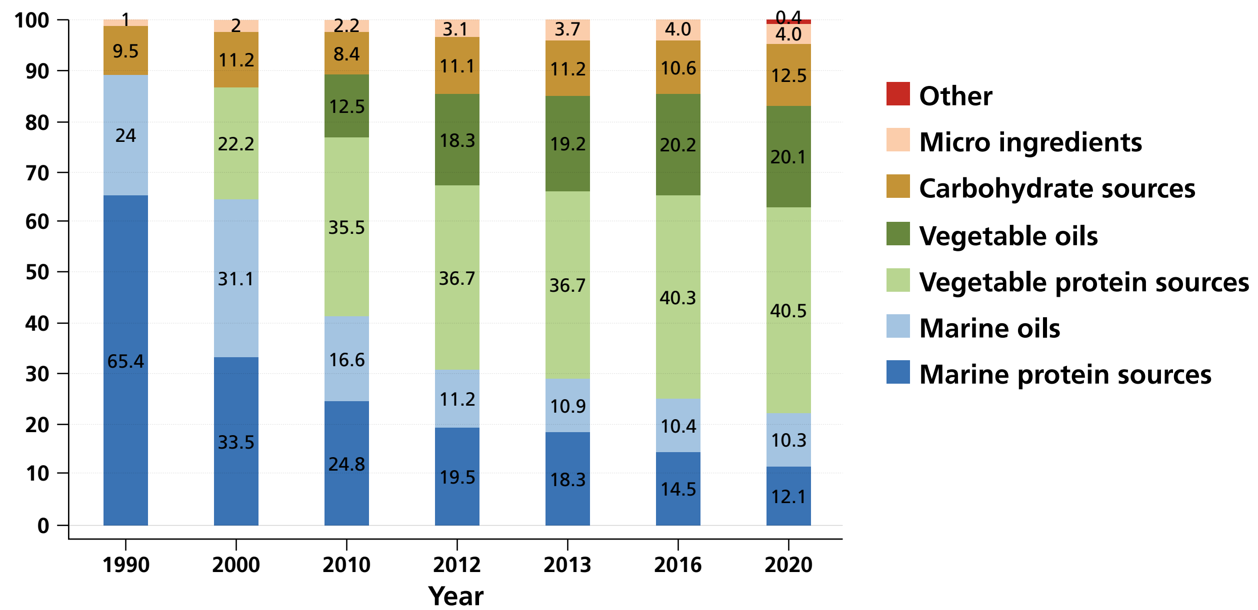


Figure 24. Sources of feed ingredients (% of feed) in Norwegian salmon through time. Micro ingredients include vitamin and mineral premixes, phosphorus sources, astaxanthin, crystalline amino acids. 'Other' includes insect meal, single-cell proteins, fermented products, and microalgae (68).

Algae

Algae-derived aquafeed ingredients, including microalgae (single-celled algae) and macroalgae (seaweeds), are promising alternatives to FMFO, particularly FO. FO derived from wild-caught forage fish can be fully replaced by oil derived from microalgae, because it provides comparable levels of essential long-chain omega-3 fatty acids (69). In contrast, FM derived from wild-caught forage fish can only partially be replaced by meal derived from macroalgae due to differences in nutritional profile and digestibility by different aquaculture species (69). Algae meal and oil are used primarily as supplemental ingredients, with inclusion rates typically kept below 10–20% to maintain fish performance and feed cost efficiency (58,69). Algae meal and oil production can have a lower environmental footprint than wild capture seafood FMFO sources, as it can be cultivated on non-arable land, using wastewater, or through open-ocean systems that require no freshwater or synthetic fertiliser inputs (70). However, high production costs, limited large-scale supply, and factors such as nutritional quality and digestibility currently constrain its broader use in aquafeeds.

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Insects

Insect meals are often promoted as a high-protein alternative to FMFO, with species such as the black soldier fly (*Hermetia illucens*) and yellow mealworm (*Tenebrio molitor*) reared on agricultural by-products, converting low-value waste into nutrient-rich feed ingredients with a small land and water footprint that do not compete with human consumption (28). However, it has been noted that insect rearing may raise animal welfare and sustainability concerns, particularly given the lack of standardised husbandry methods and the use of grains for feed, which could otherwise be destined for human consumption (71,72). For those reasons, CIWF believes insects should not be intensively farmed for use as feed for factory farmed animals. Where insects are reared on a small scale using waste streams, they should be treated in ways that respect their biological and behavioural needs and, where evidence of sentience is limited, given the benefit of doubt.

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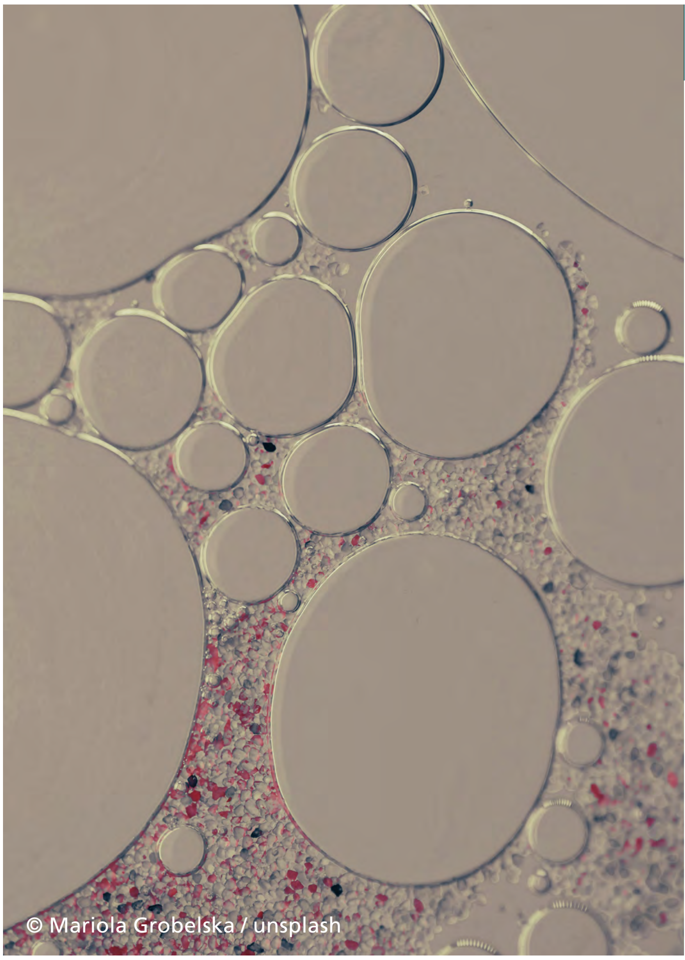
Regardless, insect farming has emerged as one of the fastest-growing alternative feed industries, supplying both aquaculture and agricultural livestock production (71). Since 2017, EU legislation has permitted processed animal protein from approved insect species in aquafeeds (73). Despite this progress, their nutritional profile – particularly low levels of essential long-chain omega-3 fatty acids – limits their ability to fully replace FMFO, and supplementation with other ingredients is often required to match FMFO nutrient profiles (58,74,75).

Beyond Europe, insect meals have proven valuable in reducing aquafeed costs where reliance on imported FMFO is high. In Zimbabwe, for example, black soldier fly larvae production has shown success in tilapia feed, cutting dependence on costly imports and creating local livelihood opportunities (76). While these benefits can make insect meals cost-competitive in some contexts, particularly where local production replaces import, in other regions higher energy demands, processing requirements, and health and safety compliance costs can limit the use of insect meal as an alternative to FMFO derived from wild-capture fisheries (77). Therefore, cost-effectively scaling production remains the primary challenge for insect meal to reduce dependence on FMFO sourced from wild-capture forage fish. It also risks diverting human-edible resources into animal feed, undermining sustainable food production. CIWF believes that welfare standards for rearing, transport, and slaughter of insects should be established to ensure the welfare is protected, and human-edible sources should not be used for the purpose of producing farmed insects.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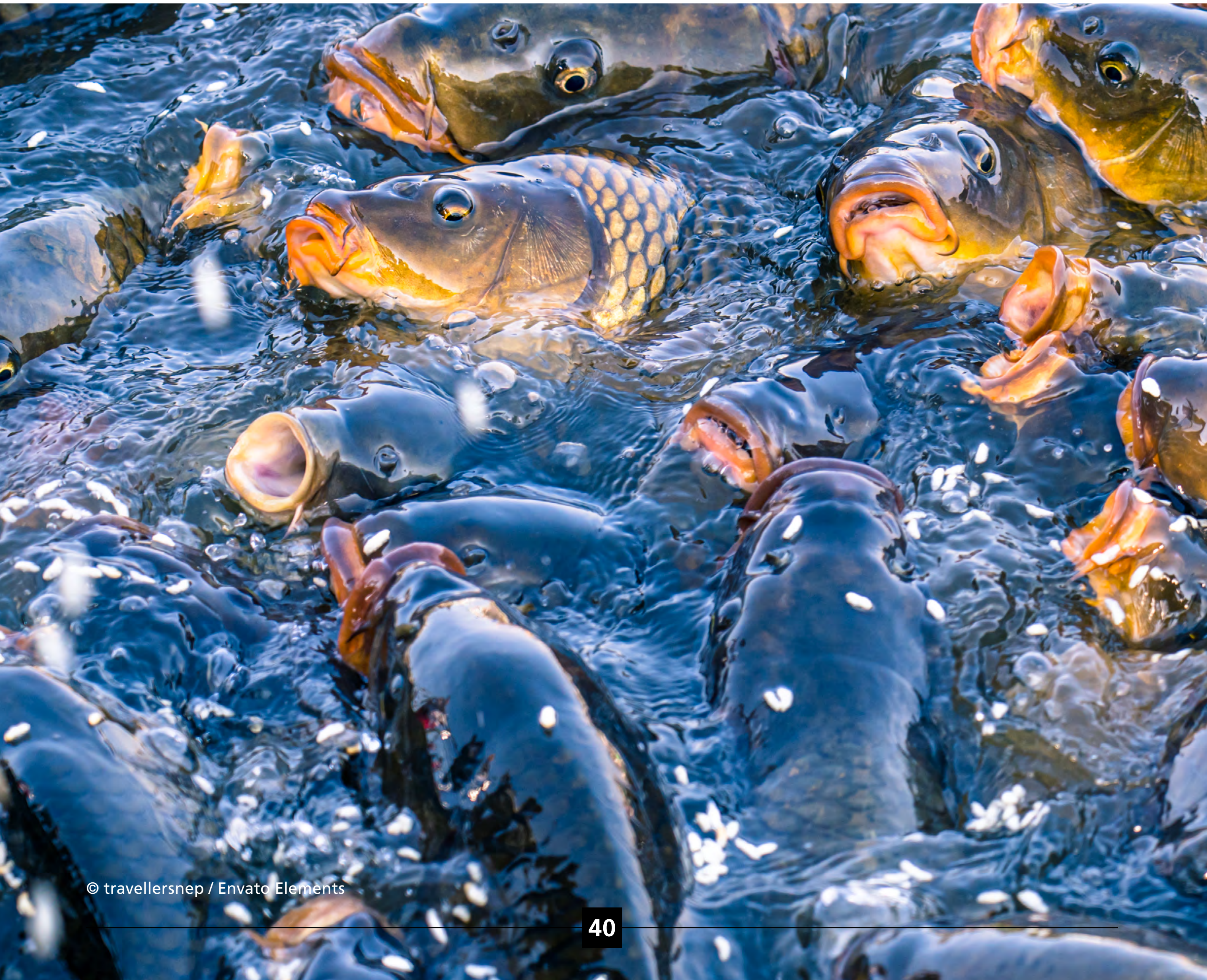
Single-cell proteins

Single-cell proteins (SCPs), derived from microalgae (mentioned in above in Algae), yeast, bacteria, and fungi, are emerging as a versatile alternative protein source for aquafeed production. Unlike most other feed ingredients, SCPs can be produced year-round in controlled environments, independent of agricultural land, climate, or season, and in some cases directly from industrial by-products (e.g., methane, ethanol, food waste) (78,79). Nutritionally, SCPs provide essential vitamins, amino acids, minerals, nucleic acids, and lipids, making them valuable alternative feed ingredients. However, their nutrient composition can vary among source organisms and may fall short of the requirements for many aquaculture species (80). Composition can, however, be tailored through source organism selection and culture conditions, a flexibility not typically possible with plant-based proteins and oils or insect meals (80). However, challenges remain as production costs for SCPs are still high relative to conventional FMFO, and other alternatives like plant-based proteins and oils.

Alternative feeds and the future

Many alternative aquafeed ingredients share common challenges, including scalability, production costs, nutrient limitations, and supply chain constraints, which limit their ability to fully replace FMFO sourced from wild-capture forage fish. From a nutritional standpoint, no single alternative mentioned above can fully match FMFO's profile, meaning a combination of alternative ingredients is often required to meet species-specific needs. Alongside this, targeted research, investment, and policy support will be critical to overcome these broader barriers and drive any future reductions in the reliance on FMFO in the aquaculture industry. Important steps that will help include:

- **Investment in production infrastructure and efficiency:** Expanding and modernising facilities, technologies, and logistics for large-scale, cost-efficient production of alternative ingredients. This includes improving processing efficiency, reducing energy use, and enhancing storage, preservation, and transport capacity to support consistent supply in both large-scale and smaller, seasonal operations.
- **Creating supportive policy and market incentives:** Developing public–private partnerships, targeted subsidies, and certification schemes that encourage adoption of alternative feeds.
- **Advancing research and innovation:** Funding research and development of ingredient blends, species-specific formulations, and novel processing methods to optimise nutritional performance and sustainability.



Looking ahead: policy pathways and recommendations

A sustainable aquaculture future will require a deliberate shift away from the intensive, high-trophic, feed-based systems toward low-trophic, extensive systems focused on filter-feeding or herbivorous organisms, such as bivalves, seaweed, and herbivorous fish. Achieving this shift will require a combination of clearly defined goals and targeted policy action.

Strategic priorities for global sustainable aquaculture

- **Shift species portfolios:** Phase out the expansion of carnivorous aquaculture reliant on wild-caught forage fish. Prioritise extensive farming systems that meet welfare needs and require little or no external feed inputs – such as bivalves, algae, and certain herbivorous fish. Low-trophic species such as carp, tilapia, and shrimp should be farmed without feeds containing FMFO, as their natural diets do not depend on these inputs.
- **Reform aquafeeds:** Phase out the use of purpose-caught wild fish, including forage fish, mesopelagic fish, krill, and other species for feed. Promote alternative feed ingredients, including fish by-products and wastes from other industries, which are not human-edible resources, and other low-impact and sustainable alternatives (i.e., microalgae, plant-based proteins).
- **Strengthen animal welfare:** Ensure that welfare protections are extended across the entire production cycle, from rearing through slaughter, including imported products. New species should only be farmed if their behavioural and physiological needs can be met in captivity. Some species are unsuitable and subsequently should not be farmed, e.g. octopus farming should be banned.

At the EU level, these priorities align closely with the Strategic Guidelines for Sustainable Aquaculture (81). To achieve these goals, a suite of policy levers can be deployed across regulatory, fiscal, and informational domains.

EU and national regulatory levers:

- Prohibit the introduction or development of new carnivorous species in aquaculture production systems, particularly those heavily reliant on wild-caught fish for feed.
- Strengthen environmental assessment and include species-specific animal welfare requirements before authorising the farming of new aquaculture species, ensuring ecological and ethical safeguards are in place.
- Establish binding feed traceability and labelling requirements, including the disclosure of FMFO composition, country of origin, species used, and sustainability certification.
- Include aquaculture operations under the scope of the EU's Industrial Emissions Directive (IED), to monitor and control nutrient discharges, greenhouse gases, and antibiotic use.
- Invest in feed innovation to reduce reliance on wild-caught inputs and scale up use of by-products and other novel low-impact alternatives.

EU fiscal levers:

- Redirect subsidies and research and development funding toward non-feed systems (e.g., algae, bivalves) and innovations that reduce reliance on wild-capture fish for feed (e.g., algae, insects, single-cell proteins, etc.).
- Introduce taxes or import tariffs on FMFO that is not sourced from certified sustainable fisheries, to discourage unsustainable sourcing practices.
- Provide targeted financial support to producers transitioning to extensive herbivorous or omnivorous systems, and to the use of alternative FMFO sources.

Informational levers:

- Incorporate sustainability and trophic level indicators in seafood labelling and national dietary guidelines.
- Implement consumer education initiatives to promote low-trophic aquaculture as sustainable dietary choices.
- Coordinate research, training, and the dissemination of best practices on farmed fish welfare across the EU.

Spain's role in advancing change

As one of the EU's leading aquaculture producers and a major importer of FMFO, Spain is uniquely positioned to shape a more sustainable future for the sector. Strategic opportunities for national leadership include:

- Banning octopus farming, as it poses serious animal welfare risks and environmental impacts. Preventing expansion into octopus farming would protect ecosystems, reduce pressure on wild fish stocks, and demonstrate Spain's leadership in advancing ethical and sustainable seafood production.
- Redirecting public subsidies away from the expansion of intensive high-trophic systems, such as octopus farming, and towards more sustainable, low-trophic alternatives.
- Embedding welfare and environmental standards in licensing criteria and seafood marketing strategies to elevate sustainability and differentiate Spanish aquaculture.
- Improve sourcing practices of FMFO derived from wild-capture resources by prioritising imports from countries that minimise ecological and social impacts, including countries with lower IUU fishing risks, higher adoption of sustainable fishing practices and compliance with RFMO obligations, and lower dependence on fish for protein.

Conclusion

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Aquaculture has become a cornerstone of the global food system, frequently framed as a solution to the rising demand for seafood. However, the analyses presented in this report highlight that the sector's continued growth, particularly in carnivorous aquaculture, carries profound ecological, ethical, and social challenges. Europe's historic and projected production of high-value, carnivorous species such as Atlantic bluefin tuna, Atlantic salmon, Rainbow trout, Gilthead seabream, and European seabass ties the industry to an unsustainable reliance on FMFO derived from wild-capture forage fisheries.

This dependence on wild-capture forage fisheries to produce the FMFO required for many aquaculture operations, exacerbates pressures on already overexploited forage fish stocks, diverts edible fish and livelihoods away from potentially vulnerable human populations, and increases the ecological footprint of European seafood consumption. Spain's sourcing practices highlight how FMFO imports from countries with high IUU risk and poor sustainable fishing practices, can magnify both ecological pressures on forage fisheries and exacerbate associated social risks in source countries. At the same time, the push to expand aquaculture into new carnivorous species, most notably octopus, illustrates how market demand is driving the sector further into ethically and environmentally unsuitable territory. The case of octopus farming in Spain has drawn international opposition, reflecting widespread recognition that farming such a highly sentient, solitary, and carnivorous species is incompatible with welfare, sustainability, and food security objectives.

Alternatives to FMFO sourced from wild-capture forage fisheries are continually evolving – ranging from seafood by-products to algae, plant-based ingredients, insect meals, and single-cell proteins. While these innovations may reduce dependence on wild-caught forage fish, they do not resolve the fundamental inefficiencies of farming high-trophic carnivorous species that require high-quality protein inputs. Moreover, many of these alternatives face significant challenges in terms of scalability and widespread adoption, and several carry their own sustainability trade-offs.

Looking forward, the future of aquaculture must be defined by a decisive transition away from intensive, high-trophic, feed-based systems toward low-trophic, extensive systems focused on filter-feeding or herbivorous organisms. Achieving this will require coordinated EU and global policies that embed animal welfare, food security, and ecological integrity at the core of aquaculture development. It will also demand greater transparency and accountability in FMFO sourcing, and the redirection of public funding away from harmful practices and towards innovation that delivers genuine benefits for animals, people, and the planet. Only by embracing these changes can aquaculture evolve into a more sustainable food system – one that protects animal welfare, safeguards marine ecosystems, and strengthens global food security.

References

1. FAO. FishStat: Global aquaculture production 1950–2022 [Internet]. 2024 [cited 2025 Jul 1]. Available from: https://www.fao.org/fishery/en/statistics/software/FishStatJ
2. Gephart J, Bejarano RA, Marks A, Gorospe K. Aquatic Resource Trade in Species [Internet]. 2024. Available from: https://knb.ecoinformatics.org/view/doi%3A10.5063%2FF1CZ35N7
3. Edwards P, Demaine H. Rural Aquaculture: Overview and Framework for Country Reviews [Internet]. Asian Institute of Technology; 1998. Available from: https://www.fao.org/4/x6941e/x6941e00.htm#Contents
4. FAO. The State of the World Fisheries and Aquaculture 2024: Blue Transformation in Action [Internet]. 2024 [cited 2025 Aug 10]. Available from: https://www.fao.org/3/cd0683en/online/sofia/2024/world-fisheries-aquaculture.html
5. Naylor R, Burke M. Aquaculture and ocean resources: Raising tigers of the sea. 2005 [cited 2025 Aug 10]; Available from: https://www.researchgate.net/publication/229000397_Aquaculture_and_ocean_resources_Raising_tigers_of_the_sea
6. FAO. The State of World Fisheries and Aquaculture: Towards Blue Transformation [Internet]. FAO; 2022 Jun [cited 2023 Dec 29]. Available from: http://www.fao.org/documents/card/en/c/cc0461en
7. Lara E. Rethinking EU Aquaculture: for people, animals and the planet [Internet]. CIWF; 2023 [cited 2025 Aug 10]. Available from: https://www.ciwf.org/resources/reports-position-papers-briefings/rethinking-eu-aquaculture-for-people-animals-and-the-planet/
8. European Commission. Directorate General for Maritime Affairs and Fisheries., EUMOFA. The EU fish market: 2022 edition. [Internet]. LU: Publications Office; 2022 [cited 2025 Aug 10]. Available from: https://data.europa.eu/doi/10.2771/716731
9. Cabello FC. Heavy use of prophylactic antibiotics in aquaculture: a growing problem for human and animal health and for the environment. Environ Microbiol. 2006 Jul;8(7):1137–44.
10. Troell M, Jonell M, Crona B. The role of seafood in sustainable and healthy diets [Internet]. Stockholm Resilience Centre; 2019. Available from: https://eatforum.org/content/uploads/2019/11/Seafood_Scoping_Report_EAT-Lancet.pdf
11. Aubin J, Papatryphon E, Van der Werf HMG, Petit J, Morvan YM. Characterisation of the environmental impact of a turbot (Scophthalmus maximus) re-circulating production system using Life Cycle Assessment. Aquaculture. 2006 Dec 11;261(4):1259–68.
12. Brown RA, Wilson RW, Tyler CR. Assessing the Benefits and Challenges of Recirculating Aquaculture Systems (RAS) for Atlantic Salmon Production. Reviews in Fisheries Science and Aquaculture [Internet]. 2024 [cited 2025 Sep 3]; Available from: https://www.tandfonline.com/doi/full/10.1080/23308249.2024.2433581
13. Philis G, Ziegler F, Gansel LC, Jansen MD, Gracey EO, Stene A. Comparing Life Cycle Assessment (LCA) of Salmonid Aquaculture Production Systems: Status and Perspectives. Sustainability. 2019 Jan;11(9):2517.
14. CIWF. Issues of Intensive Recirculating Aquaculture Systems (RAS) - Review of current literature. 2025.
15. Wang Y, Chi L, Liu Q, Xiao Y, Ma D, Xiao Z, et al. Effects of stocking density on the growth and immunity of Atlantic salmon salmo salar reared in recirculating aquaculture system (RAS). J Ocean Limnol. 2019 Jan 1;37(1):350–60.
16. Zhang Z, Fu Y, Shen F, Zhang Z, Guo H, Zhang X. Barren environment damages cognitive abilities in fish: Behavioral and transcriptome mechanisms. Science of The Total Environment. 2021 Nov 10;794:148805.
17. Alder J, Campbell B, Karpouzi V, Kaschner K, Pauly D. Forage Fish: From Ecosystems to Markets. Annual Review of Environment and Resources [Internet]. 2008 [cited 2025 Aug 10]; Available from: https://www.researchgate.net/publication/224018060_Forage_Fish_From_Ecosystems_to_Markets
18. Nissar S, Bakhtiyar Y, Arafat MY, Andrabi S, Bhat AA, Yousuf T. A review of the ecosystem services provided by the marine forage fish. Hydrobiologia. 2023 Jul 1;850(12):2871–902.
19. Changing Markets Foundation. Fishing for Catastrophe: How global aquaculture supply chains are leading to the destruction of wild fish stocks and depriving people of food in India, Vietnam, and the Gambia [Internet]. 2019. Available from: https://changingmarkets.org/wp-content/uploads/2023/10/CM-WEB-FINAL-FISHING-FOR-CATASTROPHE-2019.pdf
20. CIWF, Changing Markets Foundation. Until the Seas Run Dry [Internet]. 2019 [cited 2025 Sep 3]. Available from: https://www.ciwf.org.uk/research/species-aquatic-animals/until-the-seas-run-dry/
21. Majluf P, Matthews K, Pauly D, Skerritt DJ, Palomares MLD. A review of the global use of

fishmeal and fish oil and the Fish In:Fish Out metric. Sci Adv. 2024;10(42):eadn5650.

22. Cashion T, Le Manach F, Zeller D, Pauly D. Most fish destined for fishmeal production are food-grade fish. Fish and Fisheries. 2017;18(5):837–44.
23. Animal Charity Evaluators. Farmed Fish Welfare Report [Internet]. 2020 [cited 2025 Aug 10]. Available from: https://animalcharityevaluators.org/research/reports/farmed-fish-welfare-report/
24. Ashley PJ. Fish welfare: Current issues in aquaculture. Applied Animal Behaviour Science. 2007 May 1;104(3):199–235.
25. Southgate PJ. Welfare of Fish During Transport. In: Fish Welfare [Internet]. John Wiley & Sons, Ltd; 2008 [cited 2025 Sep 11]. p. 185–94. Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/9780470697610.ch11
26. Lines JA, Spence J. Humane harvesting and slaughter of farmed fish. Rev Sci Tech. 2014 Apr;33(1):255–64.
27. Boyland N. The Welfare of Farmed Fish during Slaughter in the European Union [Internet]. CIWF; 2018. Available from: https://www.ciwf.org.uk/media/7434891/ciwf-2018-report__the-welfare-of-farmed-fish-during-slaughter-in-the-eu.pdf
28. European Union. Consolidated Version of the Treaty on the Functioning of the European Union [Internet]. Sect. Article 13 2012. Available from: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:12012E/TXT:en:PDF
29. Mood A, Brooke P. Estimating global numbers of fishes caught from the wild annually from 2000 to 2019. Anim Welf. 2024;33:e6.
30. Tacon AGJ, Metian M. Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. Aquaculture. 2008 Dec 7;285(1):146–58.
31. Naylor RL, Hardy RW, Bureau DP, Chiu A, Elliott M, Farrell AP, et al. Feeding aquaculture in an era of finite resources. Proceedings of the National Academy of Sciences. 2009 Sep 8;106(36):15103–10.
32. Arias Schreiber M. The evolution of legal instruments and the sustainability of the Peruvian anchovy fishery. Marine Policy. 2012 Jan 1;36(1):78–89.
33. Pelletier N, Klinger DH, Sims NA, Yoshioka JR, Kittinger JN. Nutritional Attributes, Substitutability, Scalability, and Environmental Intensity of an Illustrative Subset of Current and Future Protein Sources for Aquaculture Feeds: Joint Consideration of Potential Synergies and Trade-offs. Environ Sci Technol. 2018 May 15;52(10):5532–44.
34. European Fishmeal and Fish oil Producers. Advocating for the sustainable management of the NEA Blue Whiting – European Fishmeal. European Fishmeal and Fish oil Producers [Internet]. 2025 [cited 2025 Sep 3]; Available from: https://effop.org/news-events/advocating-for-the-sustainable-management-of-the-nea-blue-whiting/
35. Holland J. England institutes ban on sandeel fishing, with Scotland ready to follow. Seafood Source [Internet]. 2024 [cited 2025 Sep 3]; Available from: https://www.seafoodsource.com/news/premium/supply-trade/england-institutes-ban-on-sandeel-fishing-with-scotland-ready-to-follow
36. European Commission. Directorate General for Maritime Affairs and Fisheries., EUMOFA. The EU fish market: 2023 edition. [Internet]. LU: Publications Office; 2023 [cited 2025 Sep 2]. Available from: https://data.europa.eu/doi/10.2771/38507
37. Medina A, Aranda G, Gherardi S, Santos A, Mèlich B, Lara M. Assessment of spawning of Atlantic bluefin tuna farmed in the western Mediterranean Sea. Aquacult Environ Interact. 2016 Feb 2;8:89–98.
38. Jelić Mrčelić G, Nerlović V, Slišković M, Zubak Čižmek I. An Overview of Atlantic Bluefin Tuna Farming Sustainability in the Mediterranean with Special Regards to the Republic of Croatia. Sustainability. 2023 Jan;15(4):2976.
39. Nardi G, Prickett R, van der Meeren T, Boyce D, Moir J. Atlantic cod aquaculture: Boom, bust, and rebirth? Journal of the World Aquaculture Society. 2021;52(3):672–90.
40. Puvanendran V, Mortensen A, Johansen LH, Kettunen A, Hansen ØJ, Henriksen E, et al. Development of cod farming in Norway: Past and current biological and market status and future prospects and directions. Reviews in Aquaculture. 2022;14(1):308–42.
41. Braham CB, Ahmed-Jeyid M, Bensbai J, Ngoum F, Corten A, Gascoigne J. Overexploitation of round sardinella may lead to the collapse of flat sardinella: What lessons can be drawn for shared stocks. Fisheries Research. 2024 Jan 1;269:106873.
42. Coetzee J, Van der Lingen C, Hutchings L, Fairweather TP. Has the fishery contributed to a major shift in the distribution of South African sardine? ICES Journal of Marine Science [Internet]. 2008 [cited 2025 Sep 2]; Available from: https://www.researchgate.net/publication/31275934_Has_the_fishery_

contributed_to_a_major_shift_in_the_distribution_of_South_African_sardine_ICES

43. Belhabib D, Cheung WWL, Kroodsma D, Lam VWY, Underwood PJ, Virdin J. Catching industrial fishing incursions into inshore waters of Africa from space. Fish and Fisheries. 2020 Mar;21(2):379–92.

44. Jacquet J, Franks B, Godfrey-Smith P, Sánchez-Suárez W. The Case Against Octopus Farming [Internet]. Issues in Science and Technology. 2019 [cited 2025 Aug 28]. Available from: https://issues.org/the-case-against-octopus-farming/

45. Gallegos C. elEconomista.es. 2023 [cited 2025 Aug 28]. Así será la primera granja de pulpos del mundo que se instalará en España con el rechazo de la ciencia. Available from: https://www.eleconomista.es/retail-consumo/noticias/12195585/03/23/Asi-sera-la-primera-granja-de-pulpos-del-mundo-que-se-instalara-en-Espana-con-el-rechazo-de-la-ciencia.html

46. Lara E. Octopus Factory Farming: A Recipe for Disaster [Internet]. CIWF; 2021 [cited 2025 Aug 28]. Available from: https://www.ciwf.com/research/octopus-factory-farming-a-recipe-for-disaster/

47. Cooke G, Tonkins B, Mather J. Care and Enrichment for Captive Cephalopods. In: The Welfare of Invertebrate Animals [Internet]. 2019 [cited 2025 Aug 28]. Available from: https://www.researchgate.net/publication/334156569_Care_and_Enrichment_for_Captive_Cephalopods

48. Villanueva R, Sykes A, Vidal E, Rosas C. Current Status and Future Challenges in Cephalopod Culture. In: Cephalopod Culture [Internet]. 2014 [cited 2025 Aug 28]. Available from: https://www.researchgate.net/publication/262943303_Current_Status_and_Future_Challenges_in_Cephalopod_Culture

49. Lara E. Uncovering the horrific reality of octopus farming [Internet]. Eurogroup for Animals and CIWF; 2023 [cited 2025 Aug 29]. Available from: https://www.ciwf.org/resources/reports-position-papers-briefings/uncovering-the-horrific-reality-of-octopus-farming/

50. Scigliano E. National Geographic. 2020 [cited 2025 Aug 28]. The world wants to eat more octopus. But is octopus farming ethical? Available from: https://www.nationalgeographic.com/animals/article/octopus-aquaculture-debate

51. García García B, Cerezo Valverde J. Optimal proportions of crabs and fish in diet for common octopus (Octopus vulgaris) ongrowing. Aquaculture. 2006 Mar 31;253(1):502–11.

52. CIWF. Devastating environmental impact of proposed octopus farm [Internet]. 2024 [cited 2025 Aug 29]. Available from: https://www.ciwf.com/media-and-news/news/devastating-environmental-impact-of-proposed-octopus-farm/

53. 5MisPeces. misPeces - Aquaculture News - Aquatic Journalism and Outreach. 2025 [cited 2025 Aug 29]. Spain Set to Debate Ban on Octopus Farming – Have We Taken It Too Far? Available from: https://www.mispeces.com/en/news/Spain-Set-to-Debate-Ban-on-Octopus-Farming-Have-We-Taken-It-Too-Far/

54. Bennet F. Octopus: aquaculture: prohibition. [Internet]. AB 3162 2024. Available from: https://leginfo.legislature.ca.gov/faces/billVotesClient.xhtml?bill_id=202320240AB3162

55. Peterson S. Prohibiting octopus farming [Internet]. HB 1153 2023. https://app.leg.wa.gov/billsummary?BillNumber=1153&Year=2023&Initiative=false

56. Sen. Whitehouse S. OCTOPUS Act of 2024 [Internet]. Jul 25, 2024. Available from: https://www.congress.gov/bill/118th-congress/senate-bill/4810

57. Love DC, Asche F, Fry J, Brown M, Nguyen L, Garlock TM, et al. Fisheries and aquaculture by-products: Case studies in Norway, United States, and Vietnam. Marine Policy. 2024 Sep 1;167:106276.

58. Hua K, Cobcroft JM, Cole A, Condon K, Jerry DR, Mangott A, et al. The Future of Aquatic Protein: Implications for Protein Sources in Aquaculture Diets. One Earth. 2019 Nov 22;1(3):316–29.

59. Peñarubia O, Toppe J, Ahern M, Ward A, Griffin M. How value addition by utilization of tilapia processing by-products can improve human nutrition and livelihood. Reviews in Aquaculture. 2023;15(S1):32–40.

60. World Economic Forum. Investigating Global Aquatic Food Loss and Waste 2024 [Internet]. 2024 [cited 2025 Aug 31]. Available from: https://www.weforum.org/publications/investigating-global-aquatic-food-loss-and-waste/

61. Kandyliari A, Mallouchos A, Papandroulakis N, Golla JP, Lam TT, Sakellari A, et al. Nutrient Composition and Fatty Acid and Protein Profiles of Selected Fish By-Products. Foods. 2020 Feb;9(2):190.

62. Council NR, Studies D on E and L, Resources B on A and N, Shrimp C on the NR of F and. Nutrient Requirements of Fish and Shrimp. National Academies Press; 2011. 810 p.

63. Love DC, Asche F, Fry J, Nguyen L, Gephart J, Garlock TM, et al. Aquatic food loss and waste rate in the United States is half of earlier estimates. Nat Food. 2023 Dec;4(12):1058–69.

64. Skavang PK, Strand AV. Conceptualization of the Norwegian feed system of farmed Atlantic salmon. Front Mar Sci [Internet]. 2024 Apr 4 [cited 2025 Aug 16];11. Available from: https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2024.1378970/full

65. Clawson G, Blanchard JL, Cormery M, Fulton B, Halpern BS, Hamilton HA, et al. Continued Transitions from Fish Meal and Oil in Aquafeeds Require Close Attention to Biodiversity Trade-Offs [Internet]. Rochester, NY: Social Science Research Network; 2024 [cited 2025 Aug 14]. Available from: https://papers.ssrn.com/abstract=5030822

66. Dreoni I, Matthews Z, Schaafsma M. The impacts of soy production on multi-dimensional well-being and ecosystem services: A systematic review. Journal of Cleaner Production. 2022 Feb 10;335:130182.

67. Chary K, van Riel AJ, Muscat A, Wilfart A, Harchaoui S, Verdegem M, et al. Transforming sustainable aquaculture by applying circularity principles. Reviews in Aquaculture. 2024;16(2):656–73.

68. Aas TS, Åsgård T, Ytrestøyl T. Utilization of feed resources in the production of Atlantic salmon (Salmo salar) in Norway: An update for 2020. Aquaculture Reports. 2022 Oct 1;26:101316.

69. Ahmad A, W. Hassan S, Banat F. An overview of microalgae biomass as a sustainable aquaculture feed ingredient: food security and circular economy. Bioengineered. 2022 Apr 1;13(4):9521–47.

70. European Commission. Towards a Strong Sustainable EU Algae Sector [Internet]. 2022 [cited 2025 Aug 12]. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52022DC0592

71. Huis. Insects as food and feed, a new emerging agricultural sector: a review. ResearchGate [Internet]. 2025 Aug 6 [cited 2025 Aug 16]; Available from: https://www.researchgate.net/publication/335431984_Insects_as_food_and_feed_a_new_emerging_agricultural_sector_a_review

72. Delvendahl N, Rumpold BA, Langen N. Edible Insects as Food-Insect Welfare and Ethical Aspects from a Consumer Perspective. Insects. 2022 Jan 25;13(2):121.

73. European Commission. Commission Regulation (EU) 2017/893 of 24 May 2017 amending Annexes I and IV to Regulation (EC) No 999/2001, and Annexes X, XIV and XV to Commission Regulation (EU) No 142/2011 regarding processed animal proteins [Internet]. Sect. L 138 2017 p. 92–116. Available from: https://eur-lex.europa.eu/eli/reg/2017/893/oj/eng

74. Makkar HPS, Tran G, Heuzé V, Ankers P. State-of-the-art on use of insects as animal feed. Animal Feed Science and Technology. 2014 Nov 1;197:1–33.

75. Gougbedji A, Detilleux J, Lalèyè PA, Francis F, Caparros Megido R. Can Insect Meal Replace Fishmeal? A Meta-Analysis of the Effects of Black Soldier Fly on Fish Growth Performances and Nutritional Values. Animals. 2022 Jan;12(13):1700.

76. FAO. Black soldier fly is helping small-scale producers in Zimbabwe to increase benefits from tilapia farming. 2023 [cited 2025 Aug 16]; Available from: https://www.fao.org/fishery/es/openasfa/19141e94-b4cc-4434-926e-3b661596e8ba

77. Hancz C, Sultana S, Nagy Z, Biró J. The Role of Insects in Sustainable Animal Feed Production for Environmentally Friendly Agriculture: A Review. Animals. 2024 Jan;14(7):1009.

78. Jones SW, Karpol A, Friedman S, Maru BT, Tracy BP. Recent advances in single cell protein use as a feed ingredient in aquaculture. Current Opinion in Biotechnology. 2020 Feb 1;61:189–97.

79. Øverland M, Skrede A. Yeast derived from lignocellulosic biomass as a sustainable feed resource for use in aquaculture. J Sci Food Agric. 2017 Feb;97(3):733–42.

80. Li YP, Ahmadi F, Kariman K, Lackner M. Recent advances and challenges in single cell protein (SCP) technologies for food and feed production. npj Sci Food. 2024 Sep 18;8(1):66.

81. European Commission. Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030. 2021. Report No.: COM(2021)236.

82. Poisson Aquatic Resource Management. IUU Fishing Risk Index [Internet]. 2024. Available from: https://www.iuufishingindex.net/

Methods

This report employed two general quantitative approaches:

1. Aquaculture production:

1. Analysis of FAO FishStatJ – Global Aquaculture Production dataset to evaluate historic trends in the sector.
2. Development of models based on historical data to project future production of carnivorous aquaculture, and in turn, project demand for forage fish.
3. Development of a model to project future production of Nueva Pescanova's proposed octopus farm under various scenarios.

2. Trade of FMFO:

1. Analysis of Aquatic Resource Trade in Species (ARTIS) data to identify major exporting and importing countries globally, across Europe, and in Spain.
2. Assessment of ecological and social impacts of Spain's sourcing patterns in 2020, and comparison with other European countries.

Aquaculture production

Historical aquaculture production

The FAO FishStatJ – Global Aquaculture Production dataset was used to investigate historical production generally by country and species at both global and European scales. These analyses provided context on aquaculture expansion and guided the selection of species to focus on for projecting future growth in carnivorous aquaculture production.

Projected carnivorous aquaculture production

Among the top 20 aquaculture species in Europe with the highest annual mean production, ten carnivorous and omnivorous species were selected to project expansion of existing carnivorous aquaculture in Europe. These species included Rainbow trout, Atlantic salmon, Common carp, Gilhead seabream, European seabass, Atlantic bluefin tuna, Turbot, Silver carp, European eel, and Bighead carp (listed in descending order of mean annual production). Since production of these species differs across country, a linear regression model was developed for each country and species from 2013 to 2023 (the last ten years of data), with projections reported as means with a 95% prediction interval to reflect uncertainty in future production estimate. Only country-species cases where at least five years of production were available were used in the analysis. These linear regressions were used to predict the future production of each country-species from 2024 to 2040. These projections were then aggregated by species and by country to assess broader trends in aquaculture production across Europe at both the species- and country-specific levels. For species-country specific slopes derived from the linear regions see Annex Table 6.

To project the future demand in forage fish from projected carnivorous aquaculture production, a literature review was conducted to collect FCRs, FM, and FO inclusion rates from wild-capture forage fish for each modelled species (Annex Table 7). Using the projected aquaculture production of the ten modelled species along with these collected statistics, demand of wild-capture forage fish (in MT) were projected using equation 1 from 2024 to 2040. Aggregated projected tonnages of forage fish were then converted into estimated number of individual fish using a conversion factor (13-30 g per fish) (29). When multiple FCRs or FM and FO inclusion rates were found for a given species, a species-specific mean was derived and used. These FCR values and FM/FO inclusion rates from forage fish represent snapshots in time and so they do not account for potential improvements in feed formulation that could reduce these values in the future.

Like projections of aquaculture production, these projections in demand for wild-capture forage fish were then aggregated by species and by country to assess broader trends across Europe at both the species- and country-specific levels. To avoid double-counting forage fish used for FM and FO, which can typically be derived from the same fish, the higher quantity (of FM or FO) was used, which typically was FO (30).

$$\text{Feed (MT)} = \text{Aquaculture Production (MT)} \times \text{FCR}$$

$$\text{FM from whole fish (MT)} = \text{Feed (MT)} \times \text{FM}_{\text{\% included from whole fish}}$$

$$\text{FO from whole fish (MT)} = \text{Feed (MT)} \times \text{FO}_{\text{\% included from whole fish}}$$

$$\text{Forage fish used for FM (MT)} = \frac{\text{FM from whole fish}}{\text{FM}_{\text{yield}} \approx 22.5\%}$$

$$\text{Forage fish used for FO (MT)} = \frac{\text{FO from whole fish}}{\text{FO}_{\text{yield}} \approx 5\%}$$

Figure 25. Equations used to predict demand for wild-capture forage fish from projected aquaculture production using species-specific FCR, FM and FO inclusion rates from wild-capture forage fish. The FM and FO yield values are widely used in the literature and industry when estimating how much whole fish is required to produce FM and FO (30).

Projected octopus aquaculture in Spain

As octopus aquaculture is a newly emerging industry with no historical production record, aquaculture production data from newly introduced carnivorous species were used. Carnivorous species introduced to Europe's aquaculture industry since 1985 were used as a reference to estimate potential production trajectories. Trophic levels were assigned to each newly introduced species with at least seven years of production data, based on values reported in the literature (Annex Table 10). Carnivorous species (trophic level ≥3.7) with at least seven years of production data from 2013 to 2013 were included in the analysis. For each species, a linear regression model was fitted to the most recent ten years of the production data (2013 to 2023) to develop these models to reflect contemporary dynamics. From these models a mean rate and 90% quantile range were calculated across carnivorous species that exhibited a positive growth rate (Figure 28), and these values were used to project octopus production forward.

Nuevo Pescanova projects an annual octopus production of 3,000 tonnes. Applying the mean growth rate exhibited by previously introduced carnivorous species aims to reflect potential expansion, likely driven by further technological development and market demand.

$$\textbf{Equation: } \text{Production}_t = 3{,}000 \text{ tonnes} + 479.5 \text{ tonnes} * (\text{year}_t - 2026)$$

The equation was used to project Nuevo Pescanova's future production of octopus production from 2026 to 2040. Given the simplicity of a linear regression these projections do not account for uncertainties such as large-scale mortalities or production failures.

Based on the projected octopus production, future demand of wild-capture forage fish was estimated using the same set of equations (Figure 25). Various scenarios were investigated including two FCRs, including FCR=2 (Nuevo Pescanova) and FCR=3 (44) and two inclusion rates of FM from forage fish, including 20% (reflecting a lower bound derived from dietary protein studies (51)) and 70% (reflecting historically high levels seen in the early development of carnivorous aquaculture feeds (30,31)). Aggregated projected tonnages of forage fish were then converted into estimated number of individual fish using a conversion factor (13-30 g per fish) (29).

FMFO Trade

The Aquatic Resource Trade in Species (ARTIS) database (2) was used to assess major exporting and importing countries of FMFO[18] derived from wild-capture fisheries at both global and European scales. To evaluate the potential ecological and social impacts associated with FMFO sourcing, indicators from the Illegal, Unreported, and Unregulated (IUU) Fishing Risk Index (82) were applied to Spain's imports in 2020 and compared with that of other European countries. The IUU Fishing Risk Index scores countries on a set of indicators linked to their exposure, vulnerability, and response capacity in relation to IUU fishing. For the purposes of assessing the ecological and social impacts of sourcing of FMFO, a subset of IUU Risk Index indicators were used, including a source country's overall IUU risk, dependence on fish for protein, adoption of sustainable fishing practices (MSC-certified fisheries), and compliance with RFMO port obligations, and dependence on fish for protein (Table 2). A weighted scoring method was employed in which each source country's score for each indicator was multiplied by the corresponding import volume (in MT), thereby incorporating both trade magnitude and impact into the assessment. The weighted scores of all source countries were summed to generate a cumulative score for each European country, enabling comparison of Spain's importing patterns in 2020 with those of the rest of Europe.

Table 2. Indicators used to assess social and environmental impacts of sourcing FMFO. Each indicator is accompanied by its underlying definition, as provided by the IUU Fishing Risk Index, along with a justification for its inclusion in the analysis.

Indicator	Underlying Description	Justification
Overall IUU Risk	Composite measure of a country's exposure to and governance of IUU fishing, including indicators of vulnerability, prevalence, and response to IUU fishing.	Reflects social, environmental, and governance risks embedded in FMFO supply chains as it relates to IUU fishing.
Dependency on fish for protein	The proportion of animal protein consumed from fish in the national diet.	Reflects the risk to national food security in countries where fish constitute a critical source of dietary protein, thereby raising ethical concerns when fish are diverted from local consumption to produce fishmeal and fish oil.
Sustainable fishing practices (MSC-certified fisheries)	The proportion of the country's total wild capture production that is MSC certified, indicating sustainable fishery practices and governance.	Serves as a proxy for sustainable fisheries management. Higher scores suggest stronger fishery management and lower ecological risk.
Compliance with RFMO port obligations	Extent to which a country implements and enforces required measures under RFMOs (e.g., port inspections, denial of port entry to IUU vessels, and data reporting, etc.).	Serves as a proxy for how effectively a country acts to prevent IUU-caught fish entering the FMFO supply chain.

18 Includes commodities: 230120 (Flours, meals and pellets; of fish or of crustaceans, molluscs or other aquatic invertebrates), 150420 (Fats and oils and their fractions; of fish, (excluding liver-oils)), and 51191 (Animal products; of fish or crustaceans, molluscs or other aquatic invertebrates and dead animals 3, unfit for human consumption).

Annex

Table 3. Annual growth rate of aquaculture production by European country. A simple linear regression was used to generate the country-specific annual growth rates from 1950 to 2023. Data source: FAO FishStatJ – Global Aquaculture Production dataset (1950–2023).

Country	Annual growth of aquaculture production (MT/year)
Norway	21,952
Spain	4,403.06
United Kingdom	3,842.01
Italy	2,885.71
Greece	2,226.04
France	2,015.35
Ireland	826.12
Croatia	687.96
Denmark	610.43
Poland	583.72
Germany	476.74
Malta	326.82
Finland	280.48
Portugal	229.41
Sweden	201.95
Cyprus	155.59
Bulgaria	118.57
Lithuania	95.71
Hungary	74.28
Czechia	69.70
Austria	52.65
Slovakia	47.64
Slovenia	29.50
Estonia	23.66
Latvia	13.66
Belgium	-1.42
Romania	-83.29
Netherlands	-401.84

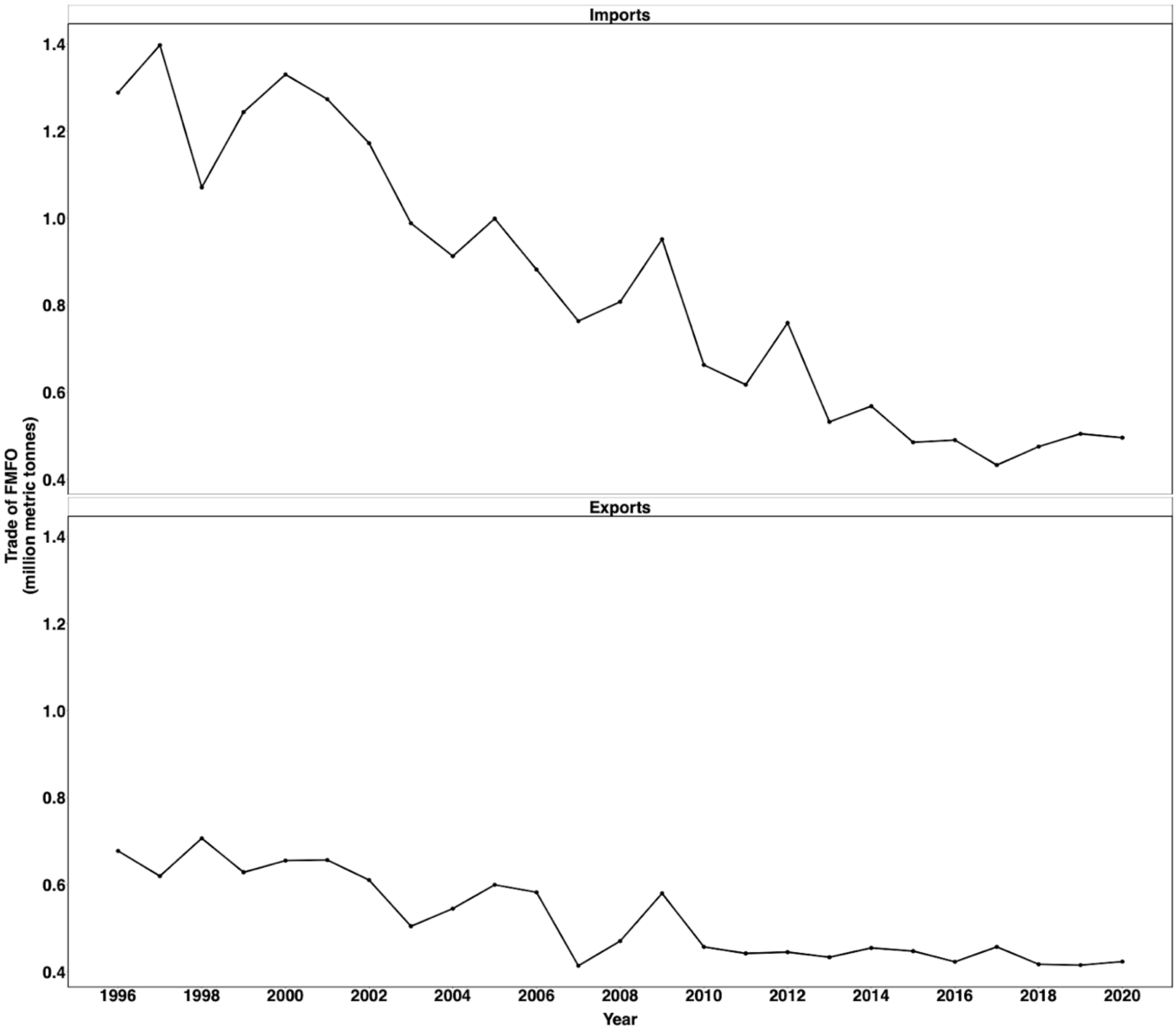
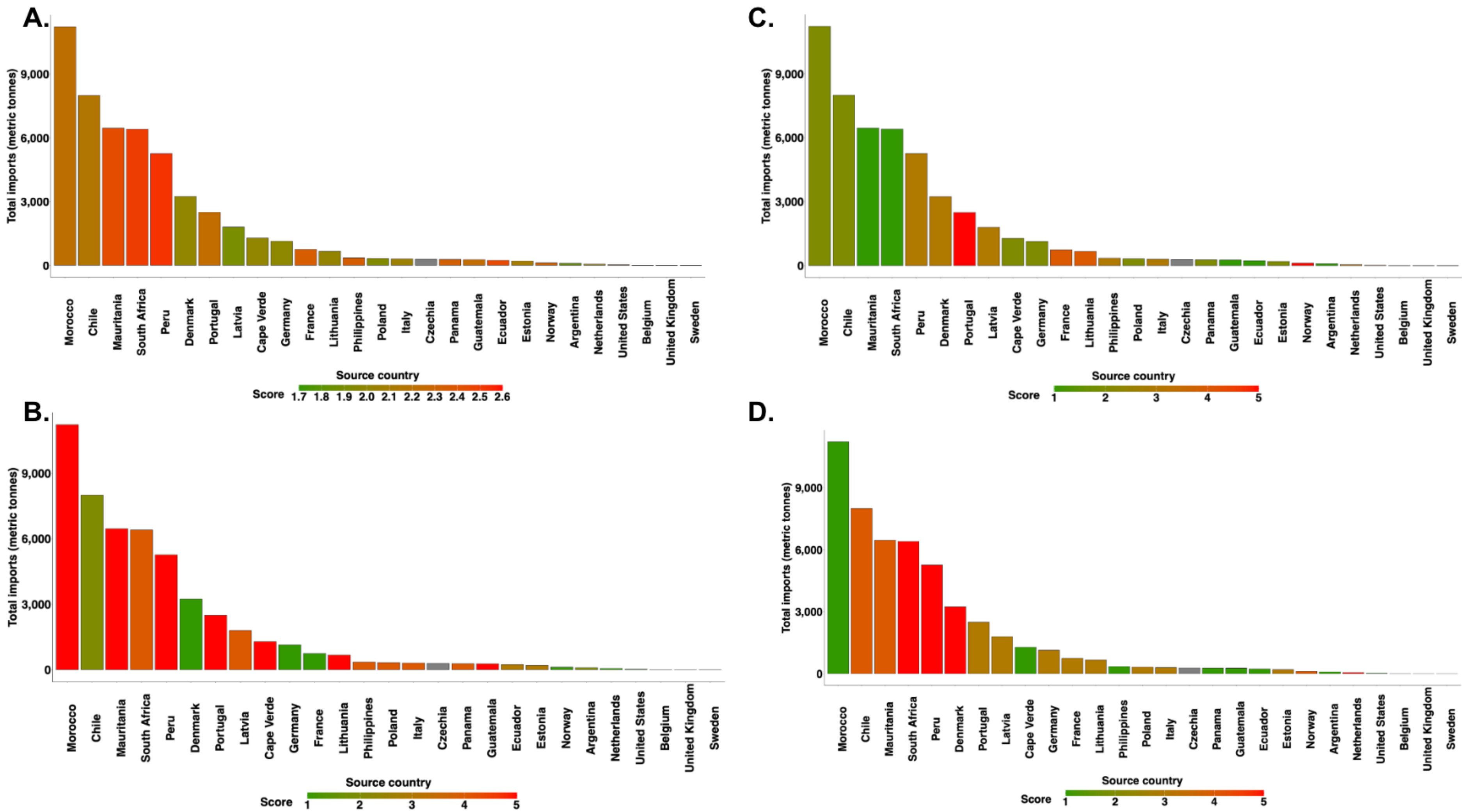


Figure 26. European imports and exports of FMFO derived from wild-capture fisheries from 1996 to 2020. Data source: ARTIS dataset.

Figure 27. Ecological and social impact of Spain's sourcing practices of FMFO derived from wild-capture fisheries in 2020, assessed across four indicators: overall IUU fishing risk (A), prevalence of MSC-certified fisheries (as a proxy for market demand for sustainable fishing practices) (B), dependence on fish for protein (C), and compliance with RFMO port obligations (D). Bar height reflects the volume of FMFO imports from each source country in 2020, while bar colour indicates the score assigned by the IUU Risk Indicator (82) for the respective indicator, with lower scores (green) denoting better performance and higher scores (red) denoting worse performance. *Note: Czechia's bar in all four panels is grey as no IUU fishing risk index data was available.*



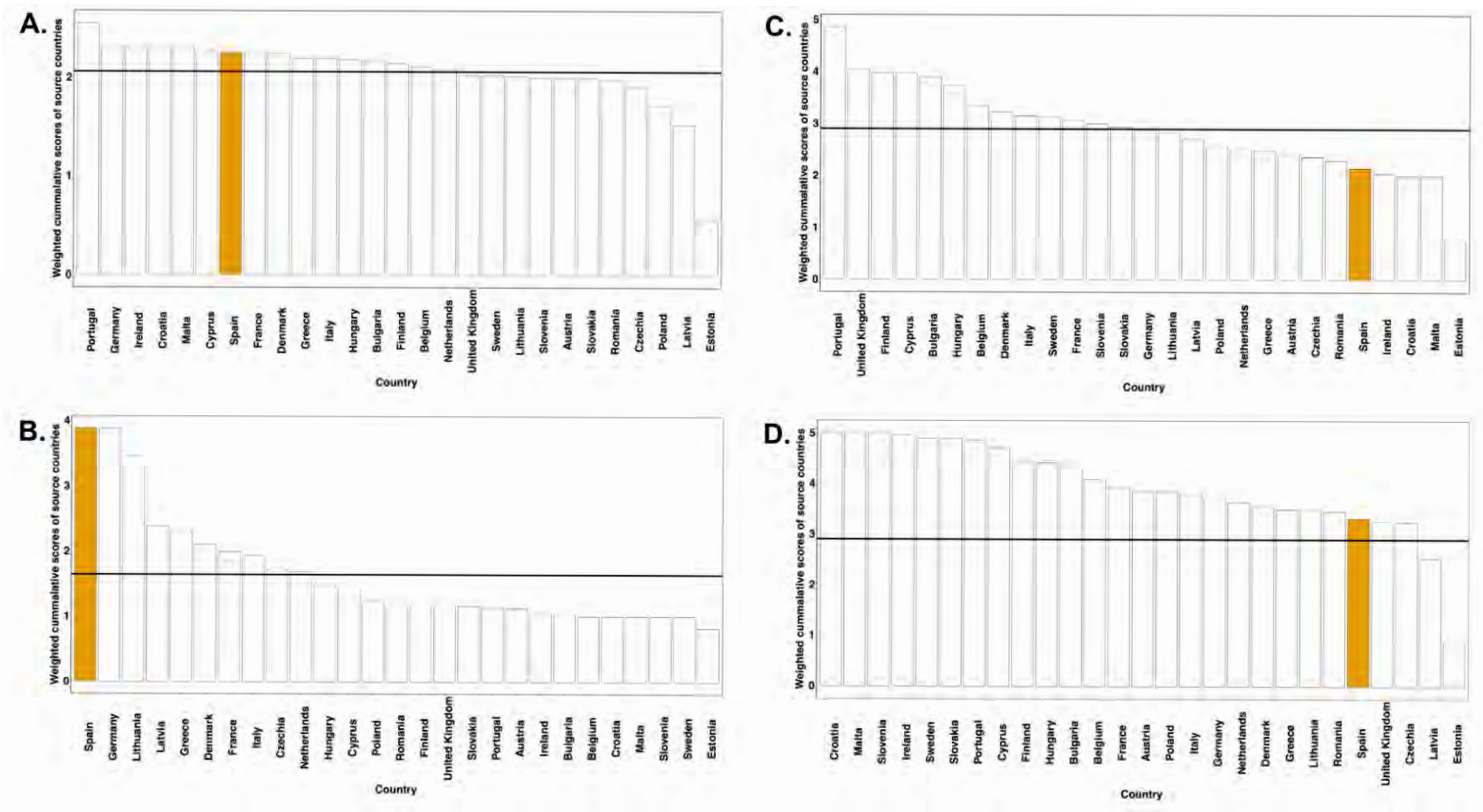


Figure 28. We weighted the cumulative score of the ecological and social impact of Spain's sourcing practices of FMFO derived from wild-capture fisheries compared to that of all European countries in 2020, assessed across four indicators: overall IUU fishing risk (A), prevalence of MSC-certified fisheries (as a proxy for market attitude towards sustainable fishing practices) (B), dependence on fish for protein (C), and compliance with RFMO port obligations (D). The height of the bar indicates a European country's weighted cumulative score of its imports from all source countries and their corresponding performance for a given indicator, where higher scores indicate poorer performance. The black horizontal line indicates the average performance across all European countries for a given indicator. The position of Spain along the x-axis indicates how it performs relative to other European countries, with placement further to the left reflecting a relatively worse performance. For further details on how these weighted scores are derived for each European country see Methods. For Spain's performance for each indicator and source country see Annex Figure 27.

Table 4. Aquaculture production in 2023 and projected production in 2040 for ten carnivorous and omnivorous species with the highest mean annual production in Europe.

Species	Aquaculture production in 2023 (MT)	Projected aquaculture production in 2040 (MT)
Rainbow trout	182,756	208,498
Atlantic salmon	161,460	207,080
Gilthead seabream	105,879	144,928
European seabass	86,546	144,167
Atlantic bluefin tuna	32,528	72,424
Common carp	63,517	57,609
Turbot	12,683	16,480
Bighead carp	3,195	4,522
European eel	2,563	4,150
Silver carp	1,626	593

*Table 5. Aquaculture production in 2023 and projected production in 2040 for ten carnivorous and omnivorous species with the highest mean annual production in Europe, aggregated by country. *For the Netherlands, no production data for these species were available for 2023 so values from 2022 are provided instead.*

Country	Aquaculture production in 2023 (MT)	Projected aquaculture production in 2040 (MT)
United Kingdom	163,547	202,836
Greece	112,428	17,3570
Spain	75,611	99,304
Italy	46,896	51,985
Croatia	23,939	48,870
Poland	36,044	48,167
Malta	20,804	40,496
France	32,459	40,166
Finland	14,426	18,472
Denmark	25,885	17,728
Czechia	16,689	15,942
Hungary	11,113	15,675
Portugal	9,292	15,606
Romania	9,635	11,893
Ireland	9,764	11,674
Cyprus	5,566	10,816
Bulgaria	8,063	10,794
Germany	12,839	7,961
Sweden	8,519	5,820
Austria	2,486	3,405
Slovakia	1,686	3,001
Lithuania	2,910	2,171
Estonia	785	1,323
Slovenia	769	1,156
Netherlands	2,150*	925
Latvia	600	695

Table 6. Slopes of species-country species aquaculture production derived from species-country specific linear regression models modeling growth in aquaculture from 2013 to 2023. Colours indicate the direction and magnitude of change, with positive slopes shown in green and negative slopes in red.

Country	Atlantic bluefin tuna	Atlantic salmon	Bighead carp	Common carp	European eel	European seabass	Gilthead seabream	Rainbow trout	Silver carp	Turbot
Austria	NA	NA	NA	-3.0840455	NA	NA	NA	63.8159909	0.03078182	NA
Bulgaria	NA	NA	-122.75248	6.40887273	NA	NA	NA	178.011464	-1.0395545	NA
Croatia	147.539273	NA	0.43936364	-18.825091	NA	662.452264	590.927936	-7.2940545	12.4338636	NA
Cyprus	0	NA	NA	NA	NA	81.6909091	105.627273	1.37145455	NA	NA
Czechia	NA	NA	-9.0636364	-121.15	0.44827586	NA	NA	18.5954545	-10.55	NA
Denmark	NA	134.345455	NA	NA	-50.069909	NA	NA	-746.99418	NA	NA
Estonia	NA	NA	NA	-2.5533431	NA	NA	NA	28.0957	NA	NA
Finland	NA	0	NA	NA	NA	NA	NA	218.476364	NA	NA
France	NA	NA	NA	-369.18203	NA	-112.48875	-76.630091	354.1762	NA	NA
Germany	NA	NA	NA	-132.77273	52.2636364	NA	NA	-203.86364	NA	NA
Greece	-14.285714	0	NA	-0.8650245	19.3689	1307.59442	1898.7861	23.0827182	NA	NA
Hungary	NA	NA	42.5018	150.529791	NA	NA	NA	2.81184545	-178.48	NA
Ireland	NA	-33.371818	NA	NA	NA	NA	NA	-44.036364	NA	NA
Italy	NA	NA	NA	-1.0454545	-29.706364	-61.887127	136.109345	113.601091	NA	2.07142857
Latvia	NA	NA	NA	4.47381818	NA	NA	NA	-0.8205455	NA	NA
Lithuania	NA	NA	4.20318182	-68.240091	NA	NA	NA	1.80190909	NA	NA
Malta	1190.07785	NA	NA	NA	0	0.14090909	-30.642636	NA	NA	0
Netherlands	NA	NA	NA	NA	-63.272727	NA	NA	0.72727273	NA	7.35E-15
Poland	NA	33.597869	22.7339643	-132.077	2.4294	NA	NA	803.670136	-44.928109	NA
Portugal	NA	NA	NA	NA	-0.0758273	112.145955	261.215591	-30.9718	NA	77.4840364
Romania	NA	NA	9.63654545	-95.090682	NA	NA	NA	249.906509	-87.938436	NA
Slovakia	NA	NA	3.86428571	44.8861818	NA	NA	NA	21.2303636	-1.5390909	NA
Slovenia	NA	NA	NA	-0.8504545	NA	-1.4190909	NA	11.4972727	NA	NA
Spain	925.265109	2.6316	NA	-0.1718	-1.0555727	886.066355	-917.46064	147.798509	NA	167.142427
Sweden	NA	NA	NA	NA	-1.9329004	NA	NA	-167.64545	NA	NA
United Kingdom	NA	663.818182	NA	-3.3002455	NA	NA	NA	-70.211509	NA	NA

Table 7. Species-specific percent inclusion of FM and FO sourced from forage fish, and FCRs.

Species	Percent inclusion of FM from whole fish	Percent inclusion of FO from whole fish	FCR	Reference/Source
Rainbow trout	13.6	1.6	1.4	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/t/seafood-watch-rainbow-trout-us-27828.pdf
Rainbow trout	13.6	1.6	1.7	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/t/seafood-watch-rainbow-trout-us-27828.pdf
Rainbow trout	4.8	4.7	1.36	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/t/seafood-watch-rainbow-trout-canada-28254.pdf
Rainbow trout	7	6.8	0.99	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/t/seafood-watch-rainbow-trout-chile-28292.pdf
European seabass	6.08	1.9	2.3	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/s/mba_seafoodwatch_seabream_seabass_meagre_report.pdf
Gilthead seabream	6.97	3.1	2	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/s/mba_seafoodwatch_seabream_seabass_meagre_report.pdf
Atlantic salmon	11.7	8.3	1.3	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/s/mba_seafoodwatch_seabream_seabass_meagre_report.pdf
Atlantic salmon	3	5	1.3	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/s/mba_seafoodwatch_seabream_seabass_meagre_report.pdf
Atlantic salmon	7.2	11.1	1.3	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/s/mba_seafoodwatch_atlantic_salmon_norway.pdf
Atlantic salmon	25.6	5.2	1.21	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/s/mba_seafoodwatch_atlantic_coho_salmon_chile.pdf
Atlantic salmon	12.3	9.3	1.21	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/s/mba_seafoodwatch_atlantic_salmon_north_america.pdf
Atlantic salmon	13.5	5.4	1.37	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/s/seafood-watch-farmed-salmon-faroes-27921.pdf
Atlantic salmon	11.7	8.3	1.3	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/s/mba_seafoodwatch_atlantic_salmon_scotland.pdf
Atlantic salmon	11.7	8.3	1.3	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/s/mba_seafoodwatch_atlantic_salmon_norway.pdf
Atlantic bluefin tuna	22.5	5	20	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/s/mba_seafoodwatch_atlantic_salmon_norway.pdf
European eel	9.36	4	1.4	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/t/mba_seafoodwatch_farmed_bluefin_tuna_mediterranean.pdf
Turbot	NA	NA	0.9	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/e/mba_seafoodwatch_eel_asia.pdf
Turbot	NA	NA	1.9	https://www.seafoodwatch.org/globalassets/sfw-data-blocks/reports/e/mba_seafoodwatch_eel_asia.pdf
Turbot	NA	NA	1.3	https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2022.1023001/full
Turbot	NA	9	NA	https://citeseerx.ist.psu.edu/document?doi=0622a2d698b11ae2a1e29f1f516e6b8adbfdda4d&repid=rep1&type=pdf
Turbot	50	NA	NA	https://www.globalseafood.org/advocate/turbot-growth-performance-on-soy-based-feeds/
Turbot	60	NA	NA	https://www.globalseafood.org/advocate/turbot-growth-performance-on-soy-based-feeds/
Turbot	30	NA	NA	https://www.globalseafood.org/advocate/turbot-growth-performance-on-soy-based-feeds/
Turbot	35	NA	NA	https://www.globalseafood.org/advocate/turbot-growth-performance-on-soy-based-feeds/
Common carp	13.5	2.6	1.1	https://www.globalseafood.org/advocate/soy-protein-concentrate-replaces-fishmeal-in-fingerling-test-diets-in-china/
Silver carp	13.5	2.6	1.1	https://www.globalseafood.org/advocate/soy-protein-concentrate-replaces-fishmeal-in-fingerling-test-diets-in-china/
Bighead carp	NA	NA	4.24	https://www.researchgate.net/publication/26519091_GROWTH_PERFORMANCE_OF_BIGHEAD_CARP_ARISTICHTHYS_NOBILIS_RICHARDSON_IN_MONOCULTURE_SYSTEM_WITH_AND_WITHOUT_SUPPLEMENTARY_FEEDING
Bighead carp	0	NA	NA	https://www.sciencedirect.com/science/article/pii/S0044848613003876
Bighead carp	12	NA	NA	https://www.sciencedirect.com/science/article/pii/S0044848613003876

Table 8. Derived use of wild-capture forage fish in 2023 and projected use of wild-capture forage fish in 2040 for ten carnivorous and omnivorous species with the highest mean annual production in Europe.

Species	Derived use of forage fish for FMFO (MT)	Projected use of forage fish for FMFO (MT)
Atlantic bluefin tuna	650,567	1,448,487
Atlantic salmon	316,190	405,528
Rainbow trout	183,019	208,797
Gilthead seabream	131,290	179,711
European seabass	75,642	126,002
Turbot	31,200	40,540
Common carp	36,332	32,953
Bighead carp	16,256	23,009
European eel	2,871	4,647
Silver carp	930	339

*Table 9. Derived use of wild-capture forage fish in 2023 and projected use of wild-capture forage fish in 2040 for ten carnivorous and omnivorous species with the highest mean annual production in Europe, aggregated by country. *For the Netherlands, no production data for these species were available for 2023, so values from 2022 are provided instead.*

Country	Derived use of forage fish for FMFO (MT)	Projected use of forage fish for FMFO (MT)
Malta	375,172	777,406
Spain	292,007	631,424
United Kingdom	308,184	386,179
Greece	122,629	188,657
Croatia	87,039	170,858
Italy	48,086	53,909
Poland	28,467	41,894
France	31,753	40,224
Portugal	14,743	23,857
Ireland	18,666	22,861
Denmark	27,106	21,576
Romania	15,522	21,466
Finland	14,447	18,499
Hungary	6,389	14,339
Cyprus	6,209	11,957
Czechia	10,763	10,006
Bulgaria	9,375	9,356
Germany	11,254	7,430
Sweden	8,537	5,835
Austria	2,246	3,173
Slovakia	1,415	2,793
Lithuania	2,431	2,303
Estonia	786	1,325
Netherlands	1,460*	1,162
Slovenia	710	1,108
Latvia	358	418

Table 10. Trophic level of species introduced to Europe's aquaculture industry since 1985.

Species	Trophic level	Source / reference
Acipenser baerii	3.3	FishBase ("Trophic level (Ref. 69278)"), page summary. (FishBase)
Acipenser gueldenstaedtii	3.3	FishBase ("Trophic level (Ref. 69278)"), page summary. (FishBase, FishBase)
Acipenser naccarii	3.4	FishBase ("Trophic level (Ref. 69278)"), species summary / key facts. (FishBase, FishBase)
Acipenser ruthenus	3.6	FishBase ("Trophic level (Ref. 69278)"), species summary / key facts. (FishBase, FishBase)
Acipenser stellatus	3.5	FishBase ("Trophic level (Ref. 69278)"), species summary / ecology page. (FishBase, FishBase, FishBase)
Alburnus alburnus	2.7	FishBase ("Trophic level (Ref. 69278)"), species summary. (FishBase)
Alburnus chalcoides	3.4	FishBase ("Trophic level (Ref. 69278)"), species summary / key facts. (FishBase, FishBase)
Argyrosomus regius	4.3	FishBase ("Trophic level … Estimated from food data"), key facts / country page. (FishBase, FishBase)
Asparagopsis spp (macroalgae)	1	NOAA/US Ocean Service—producers are trophic level 1. (FishBase/SAU do not assign TL to macroalgae.) (National Ocean Service)
Astacus astacus (noble crayfish)	NA	Not listed in FishBase/SAU for TL; SeaLifeBase describes omnivorous diet; TL varies by system in stable-isotope studies. (sealifebase.se, PMC)
Carassius carassius	3.1	FishBase ("Trophic level (Ref._69278): 3.1_±_0.24_se; based on food items.") (FishBase)
Carassius gibelio	2.5	FishBase ("Trophic level (Ref. 69278): 2.5 ± 0.0 se; based on diet studies.") (FishBase)
Carcinus aestuarii	NA	SeaLifeBase notes omnivorous feeding habits; no numeric TL found. (sealifebase.se, ResearchGate)
Chlorophyceae	1	General ecological convention—plants/algae are trophic level 1.*
Chondrostoma nasus	2	FishBase ("Trophic level (Ref. 69278): 2.0 ± 0.00 se; based on food items.") (FishBase, FishBase)
Coregonus peled	4.1	FishBase ("Trophic level (Ref. 69278): 4.1 ± 0.63 se; based on food items.") (FishBase, FishBase)
Dentex dentex	NA	FishBase page exists but lacks specific TL; related Dentex gibbosus has 4.1 ± 0.59 (FishBase)
Dicentrarchus punctatus	3.9	FishBase ("Trophic level (Ref. 69278): 3.9 ± 0.65 se; based on food items.") (FishBase, FishBase)
Diplodus puntazzo	3.2	FishBase ("Trophic level (Ref. 69278): 3.2 ± 0.0 se; based on diet studies.") (FishBase, FishBase)
Diplodus sargus	3.4	FishBase – "Trophic level (Ref._69278): 3.4 ± 0.1_se; based on diet studies." (fishbase.se)
Ensis ensis	NA	Neither FishBase nor SAU appear to provide a TL for the razor clam.
Gadus morhua (Atlantic cod)	4.1	FishBase: "Trophic level (Ref. 69278): 4.1 ±0.2 (diet studies)." (FishBase)
Gracilaria spp (red macroalgae)	1	Primary producers are TL=1 (NOAA Ocean Service). (National Ocean Service, NOAA)
Haliotis tuberculata (European abalone)	2	Generalist herbivore (abalone); herbivores are TL≈2. SeaLifeBase page + herbivory study; TL rule from NOAA. (sealifebase.ca, Wiley Online Library, National Ocean Service)
Heterobranchus longifilis _ Clarias gariepinus (hybrid catfish)	3.75	Estimate = midpoint of parents: H. longifilis TL 3.7; C. gariepinus TL 3.8 (FishBase). (FishBase)
Hippoglossus hippoglossus (Atlantic halibut)	4	FishBase: "Trophic level (Ref. 69278): 4.0 ±0.5 (diet studies)." (FishBase)
Hucho hucho (huchen)	4.2	FishBase: "Trophic level (Ref. 69278): 4.2 ±0.74." (FishBase)
Huso huso (beluga sturgeon)	4.4	FishBase: "Trophic level (Ref. 69278): 4.4 ±0.3 (diet studies)." Also shown by Sea Around Us (≈4.42). (FishBase, Sea Around Us)

Species	Trophic level	Source / reference
Ictalurus punctatus (channel catfish)	4.2	FishBase: “Trophic level (Ref. 69278): 4.2 ±0.3.” (FishBase)
Leuciscus aspius (asp)	4.4	Sea Around Us key info page (TL 4.47). (sealifebase.se)
Leuciscus idus (ide)	3.8	FishBase: “Trophic level (Ref. 69278): 3.8 ±0.59.” (FishBase)
Lota lota (burbot)	3.8	FishBase: “Trophic level (Ref. 69278): 3.8 ±0.2.” (FishBase)
Mercenaria mercenaria (hard clam / northern quahog)	2	Sea Around Us key info page (TL 2.00); filter-feeding bivalve. (Sea Around Us)
Micropterus salmoides (largemouth bass)	3.8	FishBase: “Trophic level (Ref. 69278): 3.8 ±0.4.” (FishBase)
Mimachlamys varia (variegated scallop)	2.1	Sea Around Us key info page (TL 2.10); SeaLifeBase notes suspension feeder. (Sea Around Us, sealifebase.se)
Morone chrysops _ M. saxatilis (hybrid striped bass)	4.35	Estimate = midpoint of parents: M. saxatilis TL 4.7; M. chrysops TL 4.0 (FishBase). (FishBase, FishBase)
Mylopharyngodon piceus (black carp)	3.2	FishBase: “Trophic level (Ref. 69278): 3.2 ±0.44 (molluscivore).” (FishBase)
Oreochromis niloticus (Nile tilapia)	2	FishBase (herbivorous/omnivorous; Ref. 69278)
Pagellus bogaraveo (blackspot seabream)	3.9	FishBase
Pagellus erythrinus (common pandora)	3.5	FishBase (fishbase.org)
Pagrus major (red seabream)	4.5	FishBase (fishbase.se)
Pagrus pagrus (common seabream)	3.9	FishBase (fishbase.se)
Palaemon serratus (common prawn)	2.7	Sea Around Us (ICES Journal of Marine Science)
Palaemon varians (brackish water prawn)	NA	No TL found in FishBase/SAU; noted omnivorous scavenger in ecological studies
Pelophylax ridibundus (marsh frog)	NA	Amphibian; no TL in FishBase/SAU, diet is carnivorous (insects, small vertebrates)
Penaeus indicus (Indian white prawn)	NA	No numeric TL found in FishBase/SAU; diet: benthic detritus, small inverts
Penaeus kerathurus (caramote prawn)	NA	No numeric TL found; diet: detritus and benthic invertebrates
Penaeus vannamei (Pacific white shrimp)	NA	No TL listed in FishBase/SAU; known to be omnivorous scavenger
Phaeophyceae (brown algae)	1	Producers (macroalgae = TL 1, NOAA Ocean Service)
Polititapes aureus (golden clam)	2	Filter-feeding bivalve; usually assigned TL 2 in Ecopath models
Polyodon spathula (paddlefish)	3.5	FishBase (filter-feeding zooplanktivore; Ref. 69278)
Pontastacus leptodactylus (narrow-clawed crayfish)	NA	Crustacean not covered by FishBase/SAU; omnivorous in diet studies
Rhodophyta (red algae)	1	Producers are trophic level 1; macroalgae are primary producers. (NOAA)
Saccharina latissima (sugar kelp; brown alga)	1	Producers are TL=1; macroalgae. SeaLifeBase species page confirms macroalga identity. (National Ocean Service, SeaLifeBase)
Scardinius erythrophthalmus (rudd)	2.5	FishBase species summary: “Trophic level (Ref. 69278): 2.5 ± 0.2 (diet studies).” (FishBase)
Sepia officinalis (common cuttlefish)	3.55	Sea Around Us “Key Information” lists TL = 3.55. (seaaroundus.org)

Species	Trophic level	Source / reference
Seriola lalandi (yellowtail amberjack/ kingfish)	4.2	FishBase species summary: "Trophic level (Ref. 69278): 4.2 ± 0.1." (fishbase.org)
Siganus rivulatus (marbled spinefoot)	2	FishBase species summary/ecology: herbivorous; TL = 2.0 ± 0.0. (FishBase)
Solea senegalensis (Senegalese sole)	3.3	FishBase species summary / key facts: TL = 3.3 ± 0.45 (food items). (FishBase, FishBase)
Squalius cephalus (European chub)	2.7	FishBase species summary / key facts: TL = 2.7 ± 0.13. (fishbase.org, FishBase)
Thymallus thymallus (grayling)	3.1	FishBase country/species page: TL = 3.1 ± 0.42 (food items). (fishbase.org)
Umbrina cirrosa (shi drum)	3.4	FishBase species/ecology page: TL ≈ 3.4–3.46 (diet-based). (FishBase)
Venerupis corrugata (pullet carpet shell; bivalve)	2	SeaLifeBase regional FishEco list shows TL = 2.0 for V. corrugata. (SeaLifeBase)
Aequipecten opercularis (queen scallop)	2	Filter-feeding bivalve; TL ~2 in Ecopath/SeaLifeBase models
Alitta virens (king ragworm)	2.2	Polychaete worm, deposit/suspension feeder; low TL (literature estimates)
Coregonus lavaretus (European whitefish)	3	FishBase – diet composition (zooplankton, benthos)
Pacifastacus leniusculus (signal crayfish)	2.35	Omnivorous crayfish, stable isotope studies; no fixed FishBase TL
Pecten maximus (great scallop)	2	Filter-feeding scallop; Ecopath bivalve models
Penaeus japonicus (kuruma prawn)	2.05	Ecopath model (effective TL = 2.027)
Penaeus monodon (giant tiger prawn)	2.35	Omnivorous prawn (detritus + benthic fauna); no numeric TL in FishBase
Procambarus clarkii (red swamp crayfish)	2.5	Omnivorous crayfish; stable isotope studies show flexible trophic role
Ruditapes philippinarum (Manila clam)	2	Filter-feeding clam; TL ~2 in Ecopath/SeaLifeBase
Rutilus rutilus (roach)	2.9	FishBase – omnivorous, eats plankton, benthos, plants
Salvelinus fontinalis (brook trout)	3.3	FishBase – insectivorous/piscivorous salmonid
Seriola dumerili (greater amberjack)	4.3	FishBase – large piscivore predator
Thunnus thynnus (Atlantic bluefin tuna)	4.575	FishBase (4.5 ± 0.0); Sea Around Us (4.65)
Undaria pinnatifida (wakame kelp)	1	Macroalga, primary producer
Venus verrucosa (warty venus clam)	2	Filter-feeding bivalve, TL ~2

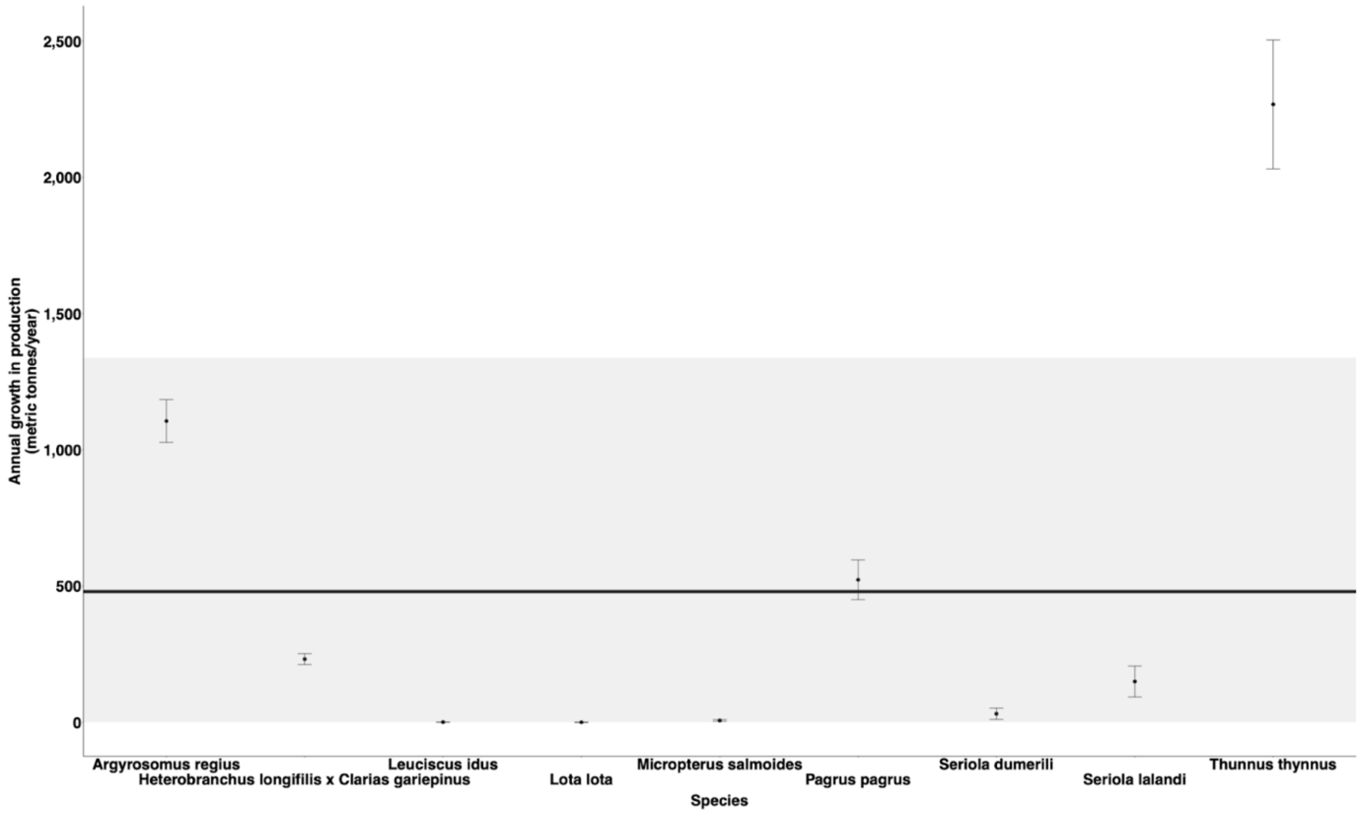
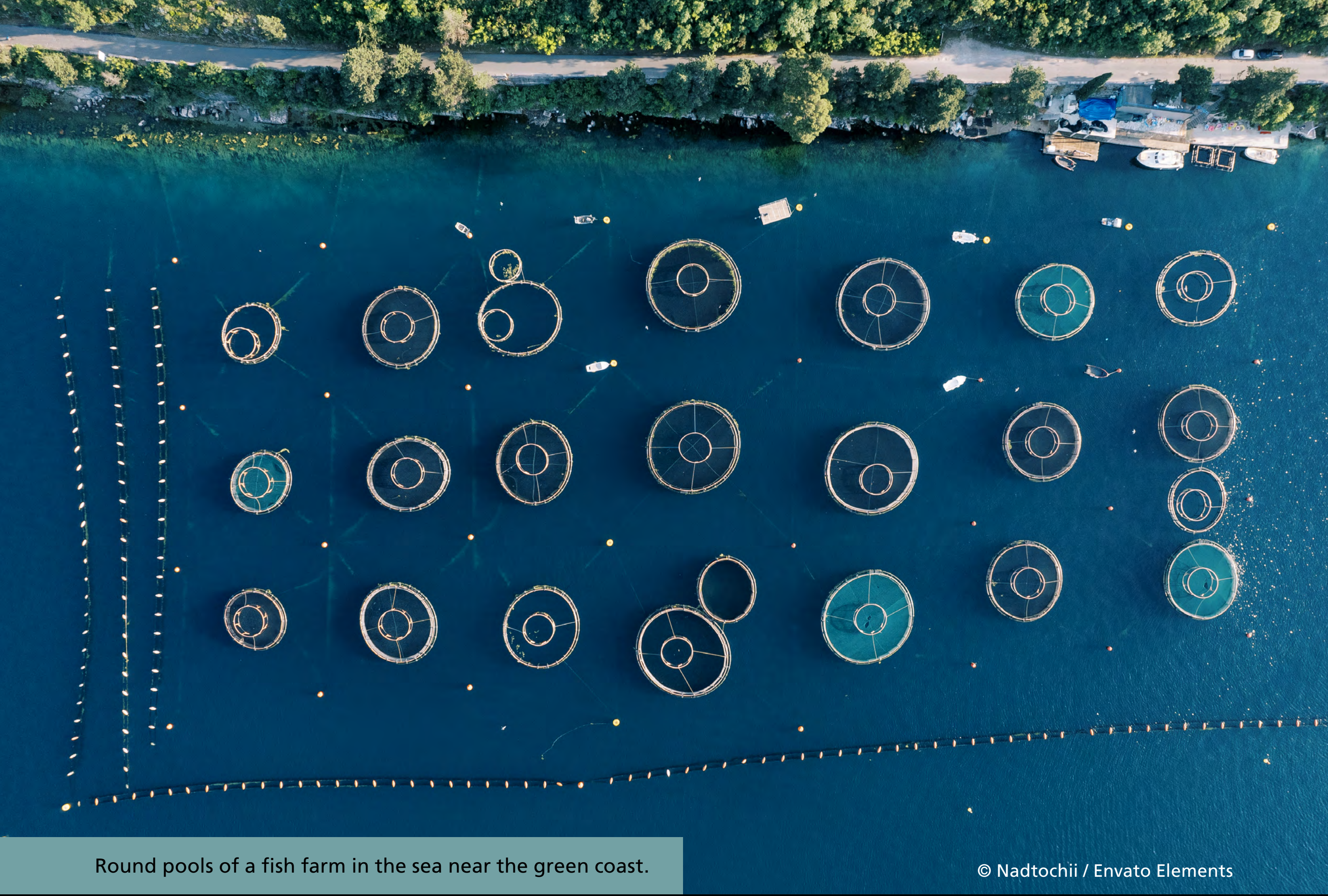


Figure 29. Growth rates of aquaculture production for carnivorous species introduced since 1985. Rates were estimated using species-specific linear regressions of aquaculture production from 2013 to 2023, restricted to species with at least seven years of production data during this time period. Points represent species-specific mean annual growth rates with error bars indicating standard errors. The solid black line shows the overall mean growth rate in production across all carnivorous species, and the shaded grey region represents the 90% quantile range. Only species with positive growth rates are included, to inform potential trajectories for octopus aquaculture expansion.



Round pools of a fish farm in the sea near the green coast.

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