IMP

Aquafeed's Protein Gap:

Mapping Supply Volatility to Protect Formula Margins

Fishmeal · Fish Oil · Alternative Proteins · Omega-3 Algae
Veramaris · Consumer Pricing · AI in Aquaculture · RAS Technology

Fishmeal Supply | Fish Oil Volatility | Protein Alternatives | Omega-3 Algae | Veramaris | AI Aquaculture | RAS Technology | Consumer Pricing | Geopolitical Risk | Sustainability

KEY FIGURES

$1,700–1,800/t
Fishmeal benchmark range 2025
$1,722/t Jul 2025 (IMF/World Bank)

+8% / –23%
2025 vs 2024 production +8%
2023 global output fell 23%

$820M
Omega-3 aquaculture market 2024
→ $1.58B by 2032 CAGR 8.5%

51M tonnes
Global aquafeed production 2023
from 15M in 2000, IFFO

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All data from publicly available sources

1 Executive Summary

Aquaculture is the world's fastest-growing food production system and one of its least-discussed. Global aquafeed production surpassed 51 million tonnes in 2023, more than tripling from 15–16 million tonnes in 2000 (IFFO). It provides protein for approximately three billion people. Yet the communication infrastructure around aquaculture — B2B marketing, investor narrative, public awareness — remains conspicuously thin relative to the sector's size and strategic importance. This paper focuses on the economics of what keeps that system running: feed ingredients, their price dynamics, their environmental cost, and the structural alternatives that are finally beginning to scale.

The central tension in aquafeed in 2026 is between a protein supply structure that cannot expand proportionally with aquaculture demand and a growing portfolio of alternatives that can — but have not yet achieved the cost, volume, or formulation stability required to displace fishmeal and fish oil at scale. Navigating this tension is the defining operational challenge for aquafeed formulators, farm managers, and the chemical industry companies supplying into the value chain.

51M t

Global aquafeed production 2023 from 15M t in 2000 (IFFO)

$1,722/t

Fishmeal benchmark Jul 2025 IMF/World Bank; range $1,700–1,800

50–70%

Feed as % of total aquaculture production costs

$1.58B

Omega-3 aquaculture market 2032 from $820M in 2024, CAGR 8.5%

The Quiet Scale Problem

Aquaculture receives a fraction of the media coverage and B2B marketing investment directed at sectors of comparable economic scale. The global salmon market alone was valued at $19–20 billion in 2024. The aquafeed input market — fishmeal, fish oil, soy protein, alternative proteins — represents tens of billions of dollars in annual procurement. Yet the category is largely invisible to the general business press and to many chemical industry clients who supply into it. The subdued communication environment does not reflect subdued stakes. Feed costs equal 50–70% of total aquaculture production costs. Every fluctuation in the fishmeal price is immediately a margin event for every farmer in the value chain.

2 The Protein Gap — Why Fishmeal Cannot Scale

Fishmeal is manufactured from whole fish or fish by-products — primarily anchovy, herring, sardines, capelin, menhaden, and blue whiting — that are cooked, pressed, dried and ground. It typically contains 60–72% crude protein with a superior amino acid profile that remains the benchmark against which all alternative proteins are measured. The fundamental structural problem is geological: the wild fish populations that supply fishmeal production cannot be expanded. They can only be managed sustainably at current levels — or depleted at higher extraction rates, which is irreversible.

Peru and Chile are the dominant producers. Peru alone accounts for approximately 20% of global fishmeal supply in an average year, with the Peruvian anchoveta fishery being the world's single largest wild-catch operation. The dependence of a global food supply system on the anchovy population off one coast — itself subject to El Niño oscillation cycles, climate-driven biomass shifts, and geopolitical trade dynamics — is the most concentrated single-point vulnerability in global aquafeed.

Country/Region	Share of Global Output	Primary Species	Key Characteristics
Peru	~20% of global fishmeal in average year	Anchoveta (Engraulis ringens)	World's largest single-species fishery. Quota-managed. Climate-sensitive — El Niño caused 23% global production decline in 2023
Chile	~10–12% of global supply	Anchoveta, jack mackerel	Second largest producer. Linked to same El Niño cycle as Peru
China	~15–18% of global supply	Multiple marine species	Domestic production declining 2025 due to rising costs. ~91% of Peruvian exports consumed in China
Norway/Iceland	~8–10%	Herring, capelin, blue whiting	High-grade product. North Atlantic fisheries recovering but quota-constrained
USA	~5%	Menhaden (Gulf/Atlantic)	Primarily domestic consumption. Omega Protein/Cooke Aquaculture dominant
Others	~30%	Regional species	South Africa, Mauritius, Faroe Islands, Spain, Denmark, UK — smaller but collectively significant

Sources: IFFO Market Research 2025; FAO GLOBFISH; IMP Analysis. Shares are average-year estimates; production is highly variable year-to-year.

2.1 The El Niño Effect: A Repeating Structural Risk

Peru opened the first 2025 anchoveta season on 22 April with a 3.0 million tonne North-Centre quota — its largest allocation since 2018. By 20 May 2025, landings had totalled approximately 1.6 million tonnes, equivalent to around 50% of the total quota (FAO GLOBFISH, Q2 2025). Available data through to season close indicates final fulfilment of approximately 82% — a reasonable outcome but materially below the 98%+ achieved in the 2024 first season, which is the figure that applies to 2024. The two seasons should not be conflated: 2024's 98%+ fulfilment represented near-complete recovery from the 2023 El Niño collapse; 2025's result reflects a large quota against a biomass that had not fully normalised. Global cumulative fishmeal production by August 2025 was still running approximately 8% above the same period in 2024 (IFFO, August 2025), confirming a continued supply recovery even with partial season fulfilment in

Period	Approximate Price (USD/t)	Context
2022	~$1,400/t	Elevated post-COVID. Supply recovering.
2023 H1	~$2,000–2,200/t	El Niño crisis. Peru season cancelled. Supply collapse.
2023 H2	~$1,900–2,100/t	Partial recovery. Markets repricing.
2024	~$1,450–1,700/t	Good Peru season (98%+ quota). Supply normalising.
2025 Q1–Q2	~$1,446–1,722/t	Continued recovery. +8% cumulative production. IMF benchmark $1,446 (Jun); any-origin avg $1,722 (Jul).
2027–2030 (IFFO projection)	$1,700–1,900/t	Assumes stable supply. Strong aquaculture demand. Price range from Procurement Tactics / IFFO analysis.

Sources: FRED/IMF PFISHUSDM series; IFFO 2025; Procurement Tactics Aug 2025; FAO GLOBFISH Q1 2025. Historical prices are benchmark averages; spot prices deviated substantially from benchmarks during 2023 crisis.

The Price Ceiling Concept

The 'price ceiling' in aquafeed formulation is the point at which an alternative protein becomes cheaper than fishmeal on an equivalent nutritional delivery basis. At $1,700–2,000/t for standard fishmeal, several alternatives — particularly fermented soy protein concentrate, selected insect meals, and single-cell proteins — cross this threshold for partial substitution in tolerant species. The ceiling is not a fixed number: it varies by species (carnivorous fish require higher fishmeal fractions), by alternative protein quality, and by the anti-nutritional factors that limit direct substitution rates. But the 2023 price spike above $2,000/t forced formulation experiments that would not have occurred at $1,400/t — and some of those formulations proved commercially viable.

3 The Alternative Protein Landscape

The search for fishmeal alternatives is not new — soybean meal has been used as a partial substitute for decades. What is new in 2026 is the breadth of the viable landscape: insect meal, single-cell proteins, fermented plant proteins, algae-based ingredients, and novel marine by-products are all now at or approaching commercial scale, with documented trial data across multiple aquaculture species. The global animal feed alternative protein market was valued at $4.9 billion in 2025 and is projected to reach $9.7 billion by 2035 (Research and Markets, CAGR 7%). Insect protein held 35.1% of this market in 2025.

Protein Source	Market Status	Price Range (USD/t)	Aquafeed Performance Notes	Category
Soybean meal (SBM)	Established — largest volume	~$450–600/t	Partial replacement at 30–50% in tolerant species. Anti-nutritional factors (ANFs) limit use in carnivorous fish. Fermented SBM (FSBM) significantly reduces ANFs, improves digestibility. US-China trade tensions create supply chain risk.	Plant-based
Insect meal (BSFL, mealworm)	Emerging — significant scalability, cost challenges. Largest player insolvent Feb 25.	~$3,500–6,000/t	*BSF larvae protein: 40–60% crude protein; excellent amino acid profile. Atlantic salmon: up to 100% fishmeal replacement without compromising quality. Most species: 25–30% partial replacement viable. IPIFF paper (2026) calls for EU mandatory inclusion targets.	Insect-derived
Single-cell protein (SCP)	Nascent — high potential Bacteria, yeast, fungi, microalgae	~$1,500–3,000/t	Produced from agricultural/dairy waste streams — circular economy. High protein content; immunomodulatory effects documented. Currently supplementary, not primary. Scalability barrier remains. Calysta FeedKind® (methane fermentation) most advanced SCP at scale.	Microbial
Fermented plant proteins (Rapeseed, pea, canola concentrates)	Scaling	~$700–1,200/t	Fermentation process removes ANFs, improves digestibility and palatability. Good amino acid augmentation when combined with synthetic amino acids. Lower cost than insect meal; better fishmeal equivalence than raw SBM. Covestro, dsm-firmenich active in this segment.	Plant-based
Marine by-products (Trimmings, krill biomass)	Established niche	~$900–1,400/t	Tuna/salmon trimmings: high protein, good palatability, proximate to fishmeal. Supply limited and concentrated geographically. Krill hydrolysate: attractant and gut health function even at low inclusion rates. Aker BioMarine dominant in krill — expanding EU distribution 2024.	Marine-derived
Microalgae protein (Spirulina, Chlorella, etc.)	Niche	~$8,000–300,000/t	**High protein content (50–70%); pigmentation benefits for salmon fillet colour. Cost remains prohibitive for bulk feed use. Primary market: specialty/premium aquaculture and shrimp hatcheries. Sun Chemical spirulina facility launched California May 2025.	Algae-derived

Sources: Research and Markets (2025); Springer Nature Discover Food (Feb 2025); European Parliament STOA (2024); Aquafeed.com; IPIFF (2026); Procurement Tactics.

*Price reality: FAIRR (2025) reports insect meal cost $3,800–6,000/t in 2023, making it approximately three times the current fishmeal price. FreezeM cites EUR 2,500–4,000/t as the target range below which aquafeed adoption becomes viable; the CEO of FreezeM stated explicitly that current prices are 'a deal breaker for aquafeed' and need to fall to approximately €2,500/t before mainstream adoption occurs (FeedNavigator 2024). The major commercial casualty of this price barrier is instructive: Ynsect — having raised $600M, the largest single investment in any insect farming company — declared insolvency in February 2025. Peer companies including Agronutris faced similar financial difficulties in early 2025 (FAIRR, March 2025). The industry has attracted approximately $1.9B in investment between 2014 and 2024 but has not achieved price parity with fishmeal. The 'approaching price parity' characterisation in an earlier version of this paper is not supported by current evidence.

**The $3,000–8,000/t range cited in earlier formulations of this paper corresponds to the very low end of commercially produced microalgae and excludes higher-value pharmaceutical and nutraceutical grades. Microalgae dry biomass prices range from approximately $8,000/t for commodity Chlorella and Spirulina to $300,000/t or above for high-purity pharmaceutical applications (IntechOpen; industry data). For aquafeed applications, the relevant economics are the DHA/EPA cost per unit of omega-3 delivered to the fish — not the biomass price per tonne — which is why comparison to fish oil must account for the higher potency of algal concentrates (Veramaris: 1t algal oil = EPA/DHA content of 60t forage fish). Bulk microalgae as a protein source for aquafeed at commercial scale remains economically unviable at current production costs.

Defensive Formulation: Swapping Without Losing Certifications

The practical challenge of alternative protein substitution is not only nutritional — it is regulatory and commercial. ASC (Aquaculture Stewardship Council) certification covered approximately 32% globally (ASC / WildFish 2025); ~40% in Norway; major North American retailers now refuse non-certified supply. Any formulation change that affects growth performance KPIs requires re-validation under the certification body's framework. Defensive formulation — the ability to swap ingredients without triggering re-certification or performance loss — requires prior qualification work, not emergency procurement decisions. Formulators who conducted insect meal trials during the 2023 fishmeal crisis were able to implement alternatives. Those without trial data were not.

4 Fish Oil and the Omega-3 Supply Constraint

Fish oil prices experienced an exceptional and well-documented spike during 2023–2024. The El Niño-driven collapse of Peruvian production in 2023 drove premium omega-3 fish oils to approximately $12,000 per tonne at their peak in late 2023/early 2024 — more than a five-fold increase from levels prevailing across the 2010s, when prices were consistently below $3,000/t (IFFO, 2024; Reviews in Fisheries and Aquaculture Science, 2024). Feed-grade aquaculture oils were substantially lower than pharmaceutical-grade premiums but still reached levels well above $7,000/t during the crisis period. By January 2025, as Peruvian supply recovered, EU import prices for fish oil had eased to approximately €2,900/t (EUMOFA Fish Market Study 2025), with further moderation expected through 2025 as the 2025 Peru season progressed. The structural implication is not the specific crisis peak but the demonstrated volatility: a price range of $2,000–12,000/t across the 2022–2024 window — depending on grade and timing — is more accurate than any single number and more instructive about the supply chain risk that feed formulators face.

Metric	Value / Range	Notes
Annual fish oil demand (aquaculture)	~700,000–800,000 t/yr	Growing ~5% annually; salmon farming accounts for largest share
Global fish oil production 2025 projection	~1.2–1.3M t	IFFO Nov 2025. Includes all uses: aquafeed, human nutrition, pet food
2023 production (El Niño year)	~1.0M t est.	–21% vs 2022. Fish oil most constrained year in recent history
Peru share of global fish oil	~30–35% in average year	Same concentration risk as fishmeal; lower oil yields in 2024–2025
Fish oil price trajectory (spot)*	Highly volatile; $2,000–3,500/t range	30%+ year-over-year swings documented; El Niño years spike sharply higher
Omega-3 aquaculture market value 2024	$820M	Growing to $1.58B by 2032, CAGR 8.5% (DataM Intelligence 2025)
Algae oil production cost reduction	~30% since 2022	Fermentation scale-up and processing improvements (Mordor Intelligence Jan 2026)

*Highly volatile by grade and period: feed-grade aquaculture oil peaked well above $7,000/t during the 2023 El Niño crisis; premium omega-3 grades reached approximately $12,000/t (IFFO 2024). Pre-2022 baseline was below $3,000/t. EU import prices eased to approximately €2,900/t by January 2025 (EUMOFA 2025). A five-fold price increase within two years is the risk profile, not a stable range.

5 Veramaris and the Algae Oil Ecosystem

Veramaris is the most prominent commercial case in the algae-based omega-3 space and the one closest to the chemical industry — founded as a 50/50 joint venture between Evonik Industries and DSM (now dsm-firmenich) in 2018, operational at its Blair, Nebraska facility from 2019. The premise: use the marine microalgae Schizochytrium sp., the original natural source of EPA and DHA in the marine food chain, to produce omega-3 oil through precision fermentation — at predictable cost, without wild fish extraction, and at the scale needed for commercial aquafeed formulation.

The technology works. One tonne of Veramaris algal oil provides as much EPA and DHA as 60 tonnes of forage fish. The Blair facility has a capacity exceeding 15,000 tonnes annually and reported a 50% production boost in 2024. Replacing 50% of fish oil in salmon feed with algal EPA maintained fillet omega-3 content above 2g per 100g while improving the feed conversion ratio from 1.25 to 1.15 — a cost saving of approximately $0.08–0.12 per kg of harvested fish (Mordor Intelligence Jan 2026). Veramaris obtained Canadian salmonid farming regulatory approval in March 2024 after a three-year registration process. Its algal oil is now incorporated into over 2 million tonnes of salmon feed worldwide.

5.1 The Honest Assessment: What Has Slowed Uptake

Despite the technical validation, Veramaris has not achieved the rapid market penetration that the technology arguably warranted. The pattern is instructive for any novel ingredient targeting a cost-sensitive industry. The production facility experienced technical challenges in early operations; production was suspended for six months to address fermentation process issues. When fish oil supply recovered after the 2023 El Niño, demand for algal oil softened as buyers reverted to cheaper fish oil. As Ian Carr, Global Business Development Director at Veramaris, stated at the North Atlantic Seafood Forum: 'With fish oil supply recovering after the last El Niño, those not specifically requiring algal oil are reverting to fish oil due to cost differences.' The market logic is rational but creates a volatile demand pattern that makes production scale-up planning difficult.

The Core Commercial Challenge for Algae Omega-3

The primary barrier to Veramaris' broader uptake is not cost per se — algae-derived EPA and DHA now match fish oil prices in concentrated forms when accounting for higher potency (Mordor Intelligence). The barrier is fish oil price volatility. When fish oil is cheap and available, buyers switch back. When it is expensive and scarce, they switch to algal oil. This cyclical demand makes long-term production investment planning difficult for algal oil producers. Veramaris' response is to position algal oil as a price hedge and stability instrument: 'The price stability of algal oil provides a dependable hedge for feed companies, offering more predictability in formulation costs.' This framing — supply chain stability rather than spot cost comparison — is the correct commercial argument, but it requires buyers to internalise long-term volatility cost in procurement decisions, which many do not.

5.2 The Competitive Landscape in Algae Omega-3

Company	Ownership	Primary Location	Approx. Capacity	Key Characteristics / 2024–2025 Developments
Veramaris	50/50 JV: Evonik Industries + dsm-firmenich	Blair, Nebraska, USA	15,000+ t/yr	Schizochytrium sp. fermentation. Dual EPA+DHA platform. Incorporated in 2M+ t salmon feed. 50% production boost 2024. Expansion planning underway. Canada approval March 2024.
Corbion / AlgaPrime	Corbion NV (Netherlands)	USA + Netherlands	Not disclosed	AlgaPrime DHA and AlgaVia DHA. China GACC approvals (human + animal) July 2025. Concentrations exceeding 50% DHA achieved. Aquaculture and infant formula partnerships.
dsm-firmenich (independent of Veramaris JV)	dsm-firmenich	Global	Not disclosed	life's DHA B54-0100 launched Oct 2024: 545mg DHA/serving. Marine lipids business sold to KD Pharma Oct 2024. Separate from Veramaris JV operations.

Aker BioMarine	Aker BioMarine ASA (Norway)	Antarctic	Not disclosed (krill harvesting)	Krill oil — phospholipid delivery benefits. Distribution partnership with Barentz for EU Oct 2024. Strategic partnerships to navigate geopolitical challenges.
BASF	BASF SE (Germany)	Multiple	Not disclosed	Fermentation IP and strain libraries. Pharmaceutical-grade concentrates. Active in algae omega-3 formulations.
MiAlgae	MiAlgae Ltd (UK)	Scotland, UK	Early stage	£14M Series A funding late 2024. Circular model: uses whisky distillery co-products. Aquafeed and supplement markets.
Fermentalg	Fermentalg SA (France)	France	Niche	Pharmaceutical-grade niches. Limited tonnage; outside mainstream feed channels.

Sources: Aquafeed.com (March 2025); Mordor Intelligence (Jan 2026); USDAnalytics (Feb 2026); Data Bridge Market Research; Evonik/Veramaris corporate.

The Long-Term Demand Signal Is Unambiguous

The global omega-3 for aquaculture market is growing at 8.5% CAGR to $1.58B by 2032. Algae omega-3 ingredients are growing at 9.2% CAGR to $3.5B by 2034 (USDAnalytics). Production costs for algae omega-3 have fallen approximately 30% since 2022 through fermentation scale-up and downstream processing improvements. The aquaculture industry cannot expand at projected growth rates if constrained by fish oil availability — the additional 20,000–30,000 tonnes of fish oil required annually are not available from wild fisheries (Veramaris NASF statement). The structural demand for algal oil alternatives is real. The commercialisation challenge is matching production investment cycles to demand that fluctuates with wild fish oil availability.

6 Supply Chain and Geopolitical Risk

The aquafeed supply chain is simultaneously a food security asset and a geopolitical exposure. Its geographic concentration — Peru/Chile for marine ingredients, Brazil/USA for soy protein, Norway/Chile/China for farmed fish — means that trade policy shifts, climate events, and regional conflicts translate directly into feed cost volatility that cannot be absorbed by thin-margin farming operations.

Risk Factor	Affected Ingredients/Products	Impact Level	Detail
Peru/Chile anchovy season variability	Fishmeal and fish oil	Critical — ~30% of global supply	El Niño 2023 caused 23% global fishmeal output decline in a single year. Repeat events are expected; climate models show increasing frequency.
China concentration in Peruvian imports	Fishmeal pricing and availability	Very High	~91% of Peruvian fishmeal exports go to China. Chinese domestic demand cycles and import policy directly set global spot prices. Any Chinese demand contraction or tariff adjustment reshapes the entire market.
US tariffs on imports (2025)	Soy protein, fishmeal from affected regions	Medium–High	25% tariffs on broad categories of US imports. Soy protein supply chains from affected trade partners disrupted. Feed grain costs elevated. US salmon aquaculture insulated domestically; export-facing US producers impacted.
Red Sea / shipping disruptions	All bulk commodity shipping	Medium	Asia–Europe freight routes affected. Fishmeal shipping from Peru/Chile to Europe and Asia faces elevated insurance and routing costs. Aker BioMarine specifically cited geopolitical challenges in their distribution strategy.
Russia–Ukraine — feed grains	Wheat, corn in compound feeds	Medium	Aquafeed uses grain-based energy sources. Black Sea grain export disruption elevated cereal costs that flow through to complex feed formulation costs.
Norway ASC certification dominance	Salmon product market access	Medium	Approximately 32% globally (ASC / WildFish 2025); ~40% in Norway. Major North American retailers refusing non-certified product. Effectively a non-tariff barrier that concentrates market access among certified producers with higher cost bases.

The China Concentration Problem

China consumes approximately 91% of Peruvian fishmeal exports and is the world's largest aquaculture producer by volume. It is simultaneously a structural demand anchor for the global fishmeal market and a single-country risk that can reprice the entire commodity within a quarter. When Chinese domestic aquaculture demand weakened in early 2024, it contributed to price normalisation globally. If Chinese policy on pork production shifts — which China announced in 2025 as an objective — it could reduce fishmeal demand from the pig sector, freeing supply for aquaculture but also complicating the price trajectory. No single variable is more important to the fishmeal market than Chinese demand behaviour.

7 Consumer Pricing and Demand Dynamics

The connection between fishmeal input costs and the price of salmon in a supermarket freezer is direct — but not proportional. Feed costs account for 50–70% of production costs, but the consumer price of farmed salmon is shaped by multiple additional layers: farm-gate price, processing margins, cold-chain logistics, retail markup, and currency effects across the Norway-to-consumer supply chain. The net effect is that retail salmon prices have increased substantially over the past five years, and the question of where demand goes when prices rise further is the central commercial question for the next generation of aquaculture investment.

7.1 Market Size and Price Trajectory

The global salmon market was valued at approximately $19–20 billion in 2024, growing at a CAGR of 8–8.8% (GMInsights; Renub Research). Global salmon volume reached 4.5 million tonnes in 2024 (IMARC Group; Expert Market Research). Norway accounts for approximately 46% of farmed salmon production. The US market has grown at 7% annually since 2013; the EU at 3% annually. Asia-Pacific is the fastest-growing consumption region, with China, Japan, and South Korea as primary drivers. In the UK, salmon is consistently the most purchased fish species by value. Supermarkets account for 54.2% of global salmon sales in 2024.

Market Segment	Current Price Condition	Evidence / Context
Salmon farm-gate price (Norway)	Strong 2024–2025	Persistently strong demand exceeding supply (Rabobank H1 2024). Producers reporting strong profitability despite feed cost pressure. Price slightly below H1 2023 record levels but historically elevated.
Retail fresh salmon (EU/US)	Significantly higher than pre-2020	No specific retail price index publicly available at frequency. Giant Eagle (US) supermarket: salmon sales +40% since 2019, reflecting volume growth. Price increases have not suppressed volume growth at current levels.
Atlantic salmon production trend	Norway: +3-4% volume growth	Volume growth continues but below demand growth trajectory. Supply discipline (biological limits, regulation) keeps prices elevated.
Shrimp — contrasting picture	Structural oversupply 2023–2025	Ecuador rapid expansion without matching demand pull. Rabobank: 'low prices may become the new normal' for shrimp. Weak China import demand a structural dampener. Different supply dynamics from salmon.
Price elasticity of demand — salmon	Relatively inelastic at current levels	Salmon positioned as premium health protein; not a commodity. WHO recommends 200g+ fish per week; omega-3 health positioning strong. Price increases to date have not reversed consumption growth trends.

7.2 The Demand Ceiling Question

The critical unresolved question is at what price point consumer demand for farmed salmon begins to contract meaningfully. Current evidence suggests this threshold has not been reached in developed markets: US salmon consumption has grown at 7% annually despite sustained price increases. The omega-3 health narrative, sushi culture adoption, and convenience packaging have supported demand against price headwinds.

The risk is at the margin: in price-sensitive market segments (value retailers, foodservice budget categories), elevated salmon prices are driving substitution toward cheaper proteins. In emerging market economies — where salmon is still aspirational rather than established — price levels that are normal in Norway or the UK represent a meaningful barrier to adoption. The long-run growth story for salmon consumption depends on the industry's ability to contain input costs through the alternative protein transition — because farmed salmon cannot grow into its addressable market if input cost inflation continuously erodes the price competitiveness that distinguishes it from wild-caught alternatives or other proteins.

7.3 The Evidence / Context

The best available proxy index is Eurostat's Harmonised Index of Consumer Prices sub-category HICP 01.1.3 "Fish and Seafood" (Euro Area), which stood at 141.17 in February 2025 (base year 2015 = 100), indicating a cumulative retail price increase of approximately 41% since 2015.

The EU's European Market Observatory for Fisheries and Aquaculture Products (EUMOFA) reports that EU consumer spending on fishery and aquaculture products reached €62.8 billion in 2024 — up 4% from 2023 — but this growth reflects higher prices, not higher volumes: at-home consumption of fresh fish fell 5% in 2024 (EUMOFA 2025 edition). Prices for fishery and aquaculture products increased more than 25% across the EU between 2020 and 2024 (EUMOFA).

The US equivalent proxy is the BLS Consumer Expenditure Survey sub-category "fish and seafood at home," which similarly shows sustained nominal price increases above general food CPI over the same period. In the EU, the volume response to price increases has been negative — consumers substituting or reducing frequency — while in North America demand has remained more volume-stable despite price inflation, reflecting different income elasticities and health positioning of salmon in the two markets.

8 Environmental Issues and Sustainability Pressures

Aquaculture's environmental record is mixed, and its sustainability credentials are contested in ways that create real commercial risk for B2B players in the supply chain. Sea lice infestation, antibiotic use, escapee fish interbreeding with wild populations, benthic impact beneath cage systems, and the wild fish input required to produce farmed fish output all appear regularly in regulatory proposals, NGO campaigns, and consumer awareness movements that affect purchasing decisions.

Environmental Issue	Definition	Status / Evidence 2025–2026
Forage Fish Dependency Ratio (FFDR)	The ratio of wild fish used as feed input to farmed fish produced.	Industry target: FFDR <1 (fewer wild fish used than farmed fish produced). ASC, WWF Basket initiative, French Earthworm programme and Walmart all require supply chains to demonstrate FFDR reduction trajectory. Algal oil substitution directly reduces FFDR — key commercial argument for Veramaris with retailers.
Sea lice and chemical treatments	Parasitic ectoparasite; major welfare and mortality risk in Atlantic salmon.	Aquabyte AI cameras counting lice in real-time and reporting to regulators. Veramaris trial documented reduced sea lice counts in salmon fed algal oil — mechanism not yet fully understood (dsm-firmenich NASF 2025). Chemical treatments (azamethiphos, hydrogen peroxide) carry environmental risk and growing regulatory scrutiny in Norway and Scotland.
Antibiotic use	Disease management in crowded aquaculture conditions.	Norwegian salmon farming: antibiotic use dramatically reduced since 1990s through vaccination programme — model case. Asian aquaculture: higher antibiotic use rates; increasing regulatory pressure. ASC and BAP certification require responsible antibiotic use documentation.
Benthic impact	Nutrient loading and organic waste deposition under sea cages.	Regulatory fallowing requirements in Norway and Scotland. RAS (land-based) systems eliminate this by design — Pure Salmon Jeddah: recycles 99% of process water. Offshore aquaculture development aimed at dispersing impact.
Wild fish in / farmed fish out	Ecological accounting for marine ingredient inputs.	In 2000: ~4–5 kg wild fish to produce 1 kg farmed salmon. In 2024: ~1.3–1.5 kg wild fish equivalent per 1 kg salmon (IFFO estimate). Ongoing improvement driven by formulation advances and alternative proteins. Target: below 1.0 — currently achievable for specific formulations.
Carbon footprint	Farmed salmon vs. other animal proteins.	Farmed salmon typically 2–4 kg CO2e/kg protein — lower than beef (~25 kg), pork (~7 kg), chicken (~4 kg). RAS systems energy-intensive but improving with renewable energy co-location. Pure Salmon Jeddah: 12–18 kWh/kg production → renewable co-location required.

The Sustainability Certification Architecture

The global aquaculture sustainability architecture is fragmented — primarily regional rather than a single global framework. Approximately 32% of global farmed salmon production is ASC certified (WildFish / conservation coalition analysis, 2025). Country-level coverage varies materially: Norway accounts for approximately 40% of its own production being ASC certified (342 ASC-certified farm sites; ASC, 2024) and provides the largest single national contribution to global ASC-certified volumes since Norway represents roughly half of global farmed salmon production. Chile reports approximately 25% coverage. The Global Salmon Initiative — whose members represent around 50% of global salmon production — has achieved approximately 60% of its member production being ASC certified (GSI statement). The global aggregate of approximately 32% is a more conservative figure than the 45% cited in some market analyses, which may reflect GSI member production rather than total global production. BAP (Best Aquaculture Practices, GSA) operates primarily in Asia-Pacific. MSC (Marine Stewardship Council) covers the wild-caught fishmeal ingredient supply. IFFO RS (Marine Ingredients Organisation Responsible Supply) covers fishmeal plants. There is no single global regulation equivalent to REACH or CBAM for aquaculture. The EU Farm to Fork Strategy and updated EU Aquaculture Strategic Guidelines provide the most rigorous regional framework. For B2B chemical industry clients supplying into aquaculture — whether feed additives, processing chemicals, or materials — ASC and IFFO RS certification chains are the primary compliance architecture to navigate.

8.1 EU Farm to Fork Strategy and the 2021–2030 Aquaculture Strategic Guidelines — Specific Challenges for B2B Chemical Industry Clients

The EU Farm to Fork Strategy (2020) and the associated Strategic Guidelines for a More Sustainable and Competitive EU Aquaculture 2021–2030 create a specific compliance architecture that extends into the B2B supply chain for chemical industry clients. The guidelines identify 13 priority areas requiring action, several of which directly affect chemical and ingredient suppliers:

Antimicrobial reduction mandate: Farm to Fork targets a 50% reduction in total EU sales of antimicrobials for farmed animals and aquaculture by 2030. For suppliers of veterinary medicines, antibiotic-containing processing aids, or hygiene additives into the aquaculture supply chain, this is a hard volume constraint on an existing revenue stream. The implication is not optional compliance — it is a market structure shift requiring portfolio reorientation toward alternatives. (probiotics, organic acids, enzyme-based pathogen management)

Pesticide and chemical input reduction: The 50% reduction target for chemical pesticide use and risk by 2030 includes chemicals used in sea lice treatment on salmon farms. Hydrogen peroxide, azamethiphos, and deltamethrin — the principal chemical treatments — face increasing regulatory scrutiny under this framework. The pipeline for chemical treatment approval in aquaculture has narrowed materially since 2020; any new chemical treatment seeking EU market access faces the full burden of proof under both the Biocidal Products Regulation (BPR) and Farm to Fork sustainability criteria simultaneously.

CSRD and CS3D supply chain disclosure: The Corporate Sustainability Reporting Directive (CSRD, effective from 2024 for large companies) and the Corporate Sustainability Due Diligence Directive (CS3D) require large companies to report on and mitigate environmental impacts through their supply chains. For chemical industry clients supplying into EU aquaculture, this means their aquaculture-operator customers will increasingly demand verified environmental data on upstream inputs — carbon intensity per tonne of additive produced, chemical hazard classifications, and documented substitution pathways for restricted substances. Suppliers who cannot provide this documentation face de-listing risk from procurement processes processes that are now compliance-driven rather than purely performance-driven.

Packaging and packaging waste (PPWR 2025/40): New EU packaging regulations require all food-contact packaging to be recyclable, specify minimum recycled content thresholds for plastic packaging, and tighten limits on substances of concern including PFAS. Aquafeed and aquaculture ingredient packaging — bags, liners, bulk containers — falls within scope. Chemical industry clients supplying packaging materials or packaging coatings into this supply chain need to have assessed their products against the 2025/40 framework.

The net effect for B2B chemical clients: the EU regulatory environment for aquaculture is not a single standard — it is an interlocking web of the Strategic Aquaculture Guidelines, Farm to Fork targets, CSRD, CS3D, PPWR, REACH, and the Biocidal Products Regulation, all operating simultaneously. Clients who are selling into EU aquaculture on the basis of product performance alone, without a mapped compliance story across this framework, are exposed to procurement de-listing risk from the largest salmon farming operations that are already integrating sustainability compliance into supplier qualification processes. The ASC certification requirement is the visible tip; the regulatory architecture beneath it is considerably more complex.

9 Technology and AI — Cost Reduction on the Farm

Aquaculture has been slower to adopt digital and AI technologies than comparable food production sectors. The reasons are structural: offshore or remote operating environments, underwater visibility challenges, heterogeneous species and farming systems, and a historically fragmented operator base of small and medium-scale farms with limited data infrastructure. This is changing. The appetite for AI in aquaculture is now described as 'high and growing by the day' by participants at Aquaculture Nexus 2025. A systematic review published in Food Chemistry X (2024) catalogued 215 research papers on AI and IoT in aquaculture from 2012–2024, mapping applications across ten core operational areas.

AI Application	Technology Description	Documented Outcomes
Precision feeding / feed optimisation	Computer vision + sonar in feed dispenser; AI models pellet detection and fish appetite signals.	ML-powered feeding: 15% reduction in operational costs through precise appetite prediction (MDPI 2025 review). Tidal X autonomous feeding system: farmer who compared autonomous vs. manual feeding at two sites and applied the autonomous system's decisions to the manual site — 'transfer of knowledge' effect. 3.7% mean percentage error in shrimp RAS feed prediction (Fish Site 2024).
Biomass and growth estimation	Camera systems measure individual fish size, aggregated to biomass estimates without manual handling.	Aquabyte smart camera: weight, biomass, weight distribution — enables precision harvest timing decisions. Aquaticode: AI phenotyping and size sorting for group homogeneity. Reduces overstocking/understocking losses.
Sea lice counting and health monitoring	AI image recognition identifying lice on individual fish through camera systems in sea pens.	Aquabyte sea lice system: automatic counting, reporting to regulator. Welfare monitoring: physical and behavioural condition assessment. Reduces need for chemical treatment through earlier detection.
Water quality management	IoT sensors monitoring dissolved oxygen, pH, temperature, ammonia, salinity in real time.	AI predictive analytics forecasting critical events before they occur. LSTM and Random Forest models for water parameter prediction. Particularly critical in RAS systems where parameter precision is higher.
Disease detection and outbreak prediction	Computer vision and ML pattern recognition identifying abnormal behaviour or visual symptoms.	Early disease detection reduces mortality and antibiotic use. ML models using historical data to predict outbreak risk. Shrimp hatcheries: AI detecting Vibrio contamination risk from water quality signals before larval mortality occurs.
RAS optimisation (land-based farming)	Full digital integration of water recirculation, feeding, growth, and energy management.	Pure Salmon Jeddah RAS: FCR 1.05 vs 1.20 sea-cage benchmark — 12.5% better feed conversion. Survival rate >95% vs 88–92% in sea cages. Recycles 99% of process water. Energy: 12–18 kWh/kg — co-location with renewables emerging as criterion.

Sources: ScienceDirect Dec 2025; MDPI Biofloc Systems Jul 2025; Aquaculture North America Sep 2025; Fish Site 2024; Mordor Intelligence Salmon Market Feb 2026.

The Role of the Chemical Industry

The chemical industry's position in aquaculture extends well beyond omega-3 additives. It encompasses feed preservatives (antioxidants to prevent lipid rancidity), amino acid supplementation (methionine, lysine — Evonik is a major supplier of amino acids to aquafeed through its Animal Nutrition segment), pigments (astaxanthin from chemical synthesis or biosynthesis for salmon fillet colour — DSM, Kemin), organic acids and probiotics (pathogen control, gut health), enzymes (phytase to improve plant protein digestibility, reducing phosphorus waste), and the processing chemistry of the feed manufacturing process itself. dsm-firmenich Animal Nutrition and Health launched a decarbonisation solution for value chains in November 2025. The chemical industry is not a peripheral supplier to aquaculture — it is embedded throughout the feed formulation and farm operation value chain.

10 The Path Through — Balance, Scaling, and the Right Trajectory

Aquaculture is not failing. It is the most efficient large-scale animal protein production system the world has built, with a feed conversion efficiency that is materially better than chicken, pork, or beef. The farmed salmon industry has reduced its wild fish input per kilogram output from approximately 4–5 kg (2000) to approximately 1.3–1.5 kg (2024). Norwegian salmon farming largely eliminated antibiotic use through vaccination decades before most protein sectors addressed the issue. ASC-certified volume now covers 32% of global production. These are real improvements made at commercial scale.

The path forward requires three simultaneous movements: concentration reduction, alternative protein scaling, and technology adoption. None of these is a quick fix, and none is possible in isolation.

Strategic Lever	What Is Required	Current Evidence / Status
Reduce geographic concentration in marine ingredient supply	Diversify sourcing from non-Peruvian fisheries; increase aquaculture of marine small pelagics; expand certified alternative supply.	First 2026 Peru anchovy quota: 1.9M t (recovering). North Atlantic herring and capelin: growing contribution. No single new source can replace Peru at volume. Requires portfolio approach.
Scale alternative proteins to commercial price parity	Insect meal: reach 2.7M t production by 2030. Single-cell proteins: close scalability gap. Fermented plant proteins: standardise performance trials.	Insect meal projected 2.7M t by 2030. IPIFF (2026) calling for EU mandatory inclusion targets. Price parity with fishmeal at >$1,700/t is achievable for partial substitution.
Secure omega-3 supply through algae oil long-term contracts	Commit to algal oil volume off-takes independent of short-term fish oil price cycles. Retailer sustainability commitments driving this.	Veramaris: planning production capacity doubling. Corbion, dsm-firmenich expanding. Algae omega-3 production costs -30% since 2022. Retailer WWF/Walmart/Earthworm commitments creating pull.
Deploy AI and precision technology to improve FCR and reduce costs	Smart feeding, RAS adoption, disease prediction, biomass optimisation.	15% operational cost reduction from ML feeding systems. RAS FCR: 1.05 vs sea cage 1.20. High initial cost barrier for small operators. Technology adoption will follow scale.
Build environmental credibility at certification and consumer level	FFDR <1 as standard formulation target. Antibiotic reduction below Norwegian levels globally. Carbon footprint reduction through renewable energy in RAS.	Retail exclusion of non-ASC product already in force (major US chains). Consumer price sensitivity growing — sustainability premium has ceiling. Regulatory direction: stricter, not softer.

On Scaling Veramaris and Algae Omega-3

Your question about whether Veramaris would achieve faster success is answered by the market structure. Veramaris launched in 2019 into a market where fish oil was abundant and cheap. The first real demand catalyst was the 2023 El Niño crisis — when buyers discovered that algal oil was available when fish oil was not. The subsequent demand softening as fish oil recovered reflects a procurement logic that is rational in the short term but collectively destructive of the investment incentive to build the alternative capacity the industry needs. The solution is long-term supply agreements that treat algal oil as a hedge instrument — stable volume, stable price, independent of wild fishery cycles. Retail commitments (WWF Basket, Earthworm, Walmart) are forcing this through the supply chain from the demand side. More players are entering: Corbion's China approvals in 2025, MiAlgae's £14M Series A, Epax's VLC-PUFA concentrate. The competitive landscape is maturing. The growth trajectory is real. The pace reflects the structural economics of competing against a volatile but historically cheap commodity.

11 Forward View — Risks, Opportunities and What to Watch

Risk / Opportunity	Probability / Horizon	Detail
El Niño recurrence	High — structural	Climate models project increasing El Niño frequency and intensity. Next severe event would again collapse fishmeal supply 20–25%. Price spike to $2,000–2,200/t would catalyse alternative protein adoption faster than any regulatory mandate.
China aquaculture demand trajectory	High	China dominates fishmeal demand (91% of Peruvian exports). Policy shifts on pork production and aquaculture regulation in China will reshape the fishmeal price curve globally.
Insect meal regulatory expansion (EU)	Medium–High	IPIFF (2026) calling for mandatory inclusion targets in EU aquafeeds. Regulatory approval for processed animal protein in feed expanding. If EU mandates minimum inclusion, insect meal market scales rapidly.
RAS cost reduction through renewable energy	Medium	12–18 kWh/kg production cost is current RAS energy burden. Co-location with solar/wind/waste heat in development. If energy cost solved, RAS becomes the dominant production model.
US tariff uncertainty	Medium	Feed ingredient supply chains disrupted. Soybean meal from affected countries repriced. US aquaculture domestic supply chain pressure.
Retail sustainability mandates tightening	Medium	Non-ASC product already excluded by major US chains. FFDR requirements likely to tighten. First retailers requiring algal oil provenance in supply chain documentation.
Algal oil production cost parity	Long-term structural	If costs continue falling at 10–15%/year, algal oil becomes cheaper than fish oil for EPA/DHA delivery at scale within 3–5 years — independent of wild fishery price cycles. This would fundamentally restructure the omega-3 supply chain.
Novel ingredients: fermentation-derived EPA via CRISPR	Emerging	2024 patent activity: CRISPR-editing Yarrowia and Schizochytrium targeting 30% fermenter-level EPA (Mordor Intelligence Jan 2026). If achieved commercially, disrupts purification economics.

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