Market Opportunity Report

Market Readiness Summary

Feed-X

December 2018

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PROJECT X

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Summary

Although the utmost care has been taken to identify and correct all typographical errors, some may still exist and if found write to info@projectxglobal.com. UK spelling is use

The most significant challenge faced by the aquaculture industry is to get access to sustainable feed ingredients at the right scale and with the right nutritional qualities

The earth consists of 70% water, but only 2% of our food is from the ocean. An ever-growing population and growing middle-class are demanding more marine protein, and as wild catch is stagnating, aquaculture is the sole alternative for responding to the increased demand for marine proteins. The most significant challenge faced by the aquaculture industry is to get access to sustainable feed ingredients at the right scale and with the right nutritional qualities.

Historically, what is the main challenge aqua feed producers have faced in feeding the future? Feed producers have faced a difficult dilemma: on one side, with decreasing supply of fishmeal and oil, and how to sustainably feed a growing population, and on the other side, how to decrease dependence on volatile marine ingredients which could otherwise be used for human consumption.

How have feed companies overcome this challenge? Since the nineties, feed producers have reduced their dependence on volatile marine ingredients, and can now produce fish feed completely without fishmeal, if need be. On average, fishmeal has been reduced from about 65% to 16%, and fish oil from about 24% to 9%. Marine ingredients are now used strategically, rather than to provide bulk protein or oil, and they are sourced from forage fisheries and fish by-products to avoid direct competition with human consumption. This way, the aquaculture industry, particularly farmed salmon, has avoided the so called “fishmeal trap” as rising demand for feed ingredients has not increased pressure on wild fish resources targeted for direct human consumption.

When one challenge is overcome, new ones can arise. Marine ingredients are now at a level where it is very hard to reduce them any further without compromising fish health, and omega-3 levels (DHA and EPA) in the fillets which are sought after by consumers. At the same time, due to consumers’ growing health consciousness, retailers are increasingly labeling omega-3 content of salmon products and sourcing organic seafood, which encourages increased usage of marine ingredients in feed. Therefore, the new challenge facing feed producers is the following: reduce marine based omega-3 in their diets, at the same time as increasing the omega-3 content in the fish. In other words, new ingredients with omega-3 content, EPA and DHA, are needed.

Can feed companies sustainably source marine ingredients? Paradoxically, yes and no. The majority of fishmeal, about 40%, comes from anchovy (whole fish) where Peru and Chile are the largest suppliers. Sourcing is highly dependent on the total allowable catch set by the Peruvian and Chilean governments each year and occurrence of El Niño. As fishmeal from whole fish has superior quality, and anchovy can be produced more cheaply than whole fish from menhaden, jack mackerel and herring, we only expect whole fish to be marginally substituted by by-product. Aquaculture uses about 73% of all fish oil, and 70% of all fishmeal available, and it is a challenge to source from sustainable fisheries as only 14% of fish caught for all uses were MSC-certified in 2017, and only 45% of fishmeal and oil produced globally was certified to IFFO. We need to find new alternatives.

We are facing the same old dilemma. We are currently at a crossroad. Looking to the past, global production of fishmeal and oil has declined over the last 30 years - fish oil more than fishmeal. Looking to the future, fishmeal and oil are expected to stabilise over the following years. Aquaculture, however, is forecasted to grow by ~3.6% per year due to increased demand, which is projected to lead to increased demand for marine ingredients in feed. Arguably, fishmeal usage could be further reduced to decrease impacts on the marine environment from fishing, but also because fishmeal is not an essential feed ingredient in itself. However, this is not ideal as it is a cost-effective, excellent source of highly digestible protein, beneficial fatty acids and essential vitamins and minerals.

Sources: PwC Seafood analysis

The current rate of fish oil inclusion is not sustainable if feed production is to grow in line with projected annual aquaculture growth

Fish oil, not fishmeal, is the x-factor. Fish oil is a scarce resource. Fish oil provides the long-chain omega-3 fatty acids, EPA and DHA, which are considered valuable for rapid animal growth, and are increasingly marketed for direct human consumption as nutraceuticals due to health and medical benefits. The four big feed companies, Skretting, Marine Harvest Feed, Cargill Aqua Nutrition and Biomar, currently source ~60% of total fish oil supply. If this usage is to keep up with the 3.6% growth rate in aquaculture, the same companies will source an estimated 98% of total supply in 2030[1]. Considering competition from other feed companies, and from direct human consumption, a segment which is willing to pay more for fish oil, the current rate of inclusion in feed is not sustainable. To add to the challenge, fish oil is now at a level which is very hard to reduce without novel ingredients.

Can't we just use vegetable ingredients instead? Again, yes and no. Originally, fish feed did not include any vegetable protein and oils, except for starch as pellet binder. To decrease dependence on fishmeal and oil, vegetable ingredients, like soybean protein concentrate, has increasingly substituted fishmeal to a point where the feed industry is now dependent on soy instead of fishmeal. Currently, the big four feed companies' feed contain an average of 19% vegetable oils, and 40% vegetable meal. Vegetable ingredient-based diets can affect the intestinal flora and immune defenses and overall health status of the fish. Although plant ingredients do not have the same supply restrictions as fishmeal and oil, there is no evidence that they are inherently more sustainable for fish farming, provided marine feed ingredients are sourced from sustainably managed stocks (or from fishery by-products).

Soybean sourcing is a minefield. Soybeans are fraught with negative externalities. They have led to large areas of soybean monoculture and the subsequent heavy use of chemicals has led to soil degradation and water contamination. The Cerrado rainforest has been destroyed for soy plantations. As there is a soy moratorium in the Amazon, it is no longer the driver of deforestation in that area. However, this has increased the pressure of deforestation in the Cerrado which is next door to the Amazon basin. The majority of soybeans produced are genetically modified, which is not accepted by consumers in many countries, for example in Europe. There are many environmental standards for sustainable soy production, and there has been no real agreement and a lack of widespread industry support. However, industry consensus is emerging. Marine Harvest Feed and Skretting claim that 100% of their soy is certified ProTerra. Cargill Aqua Nutrition and Biomar, however, have 74% and 78% respectively. If soy protein concentrate usage is to grow in line with the 3.6% growth rate, it is absolutely necessary that sustainability certifications of soy grows as fast, or faster, than demand.

How can we replace or supplement fishmeal, fish oil and soy? It is not going to be easy, but it is doable. The main challenge is that novel ingredients are not yet scalable, and as long as they are more expensive than fishmeal and oil, they will not be competitive from a commercial viewpoint. Bearing in mind the price increase trend for fishmeal and oil, we think this is about to change. The question is, who, in the aquaculture value chain, is willing to take on the increased risk and costs of adopting such novel ingredients in the short term? The success of adoption and scalability depends on cooperation throughout the whole value chain. In the end, it will benefit all.

Notes: 1 Assuming constant supply of fish oil from 2015-levels, and constant market share of producers and share of fish oil in production
Sources: PwC Seafood analysis

Micro-algae and microbial protein are the most likely contenders to transform the feed value chain by 2030

Which novel ingredients are the most promising to replace or supplement fish oil? According to feed and industry experts, genetically modified oilseed crops, and single-cell or micro-algae oils, are the most promising in terms of growth potential. In fact, all the four big feed companies have invested in, and/or are researching, micro-algae as replacement for fish oil. Another promising source of omega-3, and replacement and/or supplement for fish oil and rapeseed oil, is non-GM camelina oil. Camelina oil can be grown in colder environments like Canada and Russia, but it is currently grown in very small volumes. GM-canola oil is another promising alternative which will shortly be available for fish farmers in Canada and Chile. However, as with all GM-ingredients, it faces opposition in Europe. Many countries have banned the production, transport, and sales of GM canola.

Krill, if sourced sustainably, could be an excellent source of omega-3 (DHA and EPA). As only about 1% of krill is harvested globally, it has insignificant volumes available and is therefore very expensive. Aker Biomarine supplies about 60% (~158,000 tonnes) of harvested krill, and has an exclusivity agreement with Biomar, making krill even more inaccessible to other feed producers. Krill fisheries have also been criticised for operating in the vicinity of penguin colonies and whale feeding grounds. Mesopelagic fish is another alternative. There is a large unexploited biomass of mesopelagic fish living in the deep ocean. This biomass has recently been estimated to 10 billion metric tons. The real biomass is still in question, and it will take years of research before one can begin to sustainably harvest this source due to lack of knowledge on this species and its environment.

Which novel ingredients are the most promising to replace or supplement fishmeal? Microbial ingredients and protein (bacteria, yeast), show strong potential as replacement and/or supplement to fishmeal. Calysta's FeedKind requires no agricultural land, a fraction of the fresh water required by traditional agricultural products, and it does not compete with the human food chain. The downside is that its current energy source is methane from fracking, an energy source criticised for heavily polluting the environment. Insect-based protein is another strong potential as alternative to fishmeal. It has a favorable nutrient content, and grows on animal manure or waste and therefore has a direct conversion of waste to valuable nutrients. Still, it can be challenging to scale up, and insect-based proteins have been categorised as animal by-product (processed animal protein) in Europe, placing it in the same category as poultry and blood meal. Although approved by the EU as feed ingredient for aquatic species since July 2017, this ingredient is not yet fully accepted by retailers and consumers in Europe. In the long-term, we expect insect meal to be scaled up in sufficient quantities.

To conclude. In the short to medium-term, and within the transformation period leading up to 2030, we believe the ingredient most likely to replace and supplement fish oil will be micro-algae, and for fishmeal, microbial protein from bacteria and yeast. In addition to adopting alternative ingredients, we also believe that transforming current, unsustainable sources of soy and marine ingredients is a minimum requirement to reach the Feed-X goal. Ideally, if all aqua feed producers transform 10% of their production by 2030, a total of 6.5 million tonnes of feed must be transformed and sustainably produced. In order to achieve this goal, it is absolutely vital that the big four, Skretting, Marine Harvest Feed, Biomar and Cargill Aqua Nutrition, lead the way, as they historically have, and take responsibility for this transformation. Therefore, we encourage the big four to transform more than 10% of their value chains by 2030. More importantly, we encourage all players in the value chains, specifically salmonid and shrimp farmers, innovators, regulators, retailers and the end consumers, to welcome and aid in this transformation.

Sources: PwC Seafood analysis

Project X' goal is to transform 10% of the global feed industry by adopting alternative feed ingredients

FEED-X

Target

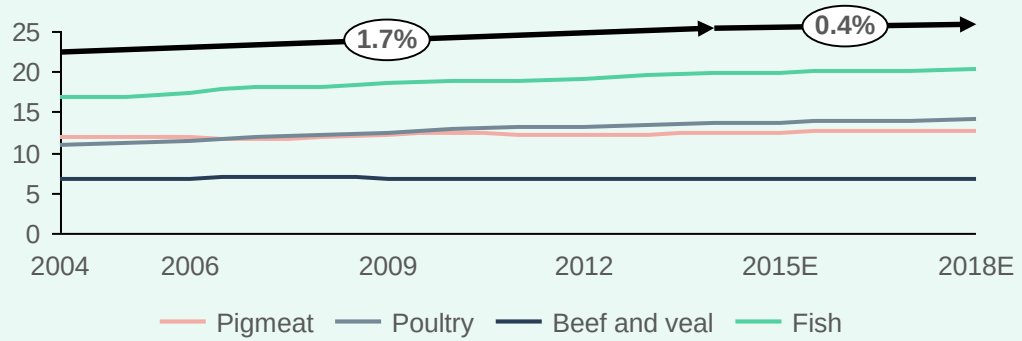
10% of the global feed industry to adopt alternative feed ingredients into value chains (purchase order for test or outright procurement)

Important to keep in mind that:

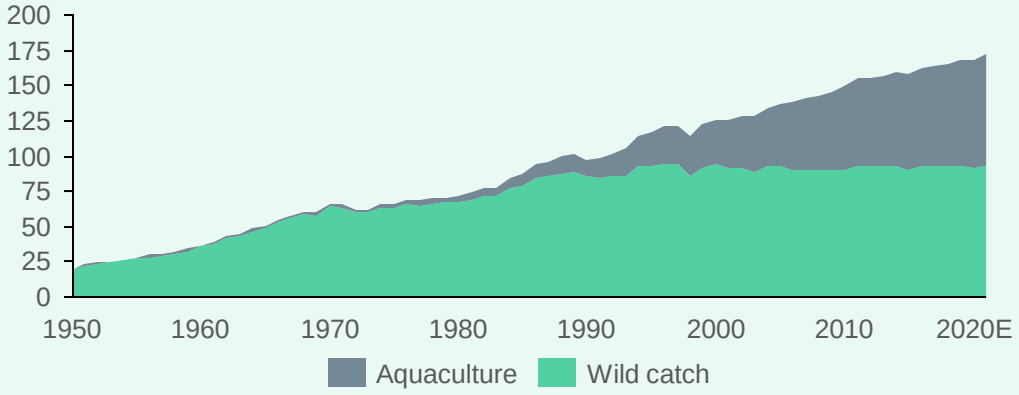
- The market opportunity report was made in 2018 (recent developments are not included)
- Numbers are from 2016, and from publicly available sources (e.g. annual reports, sustainability reports, etc.)
- This is a summary report and a fuller version is available on request

Global fish consumption is increasing whilst fish stocks are depleted, and aquaculture appears to be the only replacement

Global Consumption per Capita (KG per Capita)



Global Seafood Production (1950–2020E,* million tonnes live weight)



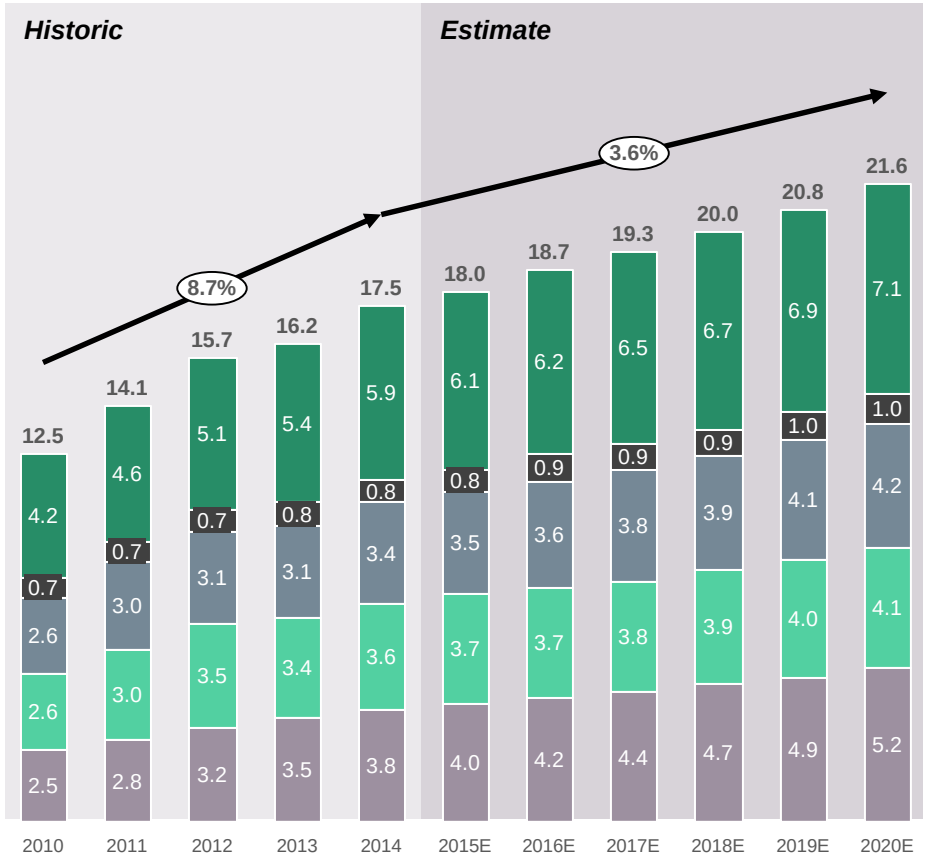
- **Fish consumption** provides more than 1.5 billion people with 20% of their average intake of protein, and 3 billion with over 15%
- The average yearly consumption of **fish per capita** is 19 kg
- Europe constituted 35% of the seafood market in 2007, but only 10% of world population – highlighting the **potential in other regions to increase per capita consumption**
- Based on expected income growth, there will be a **seafood deficit** by 2030 of around **79 million tonnes**
- Consumption growth is expected to be boosted by **developing economies** moving to **protein rich** diets and **developed economies** seeking **healthier, environmentally friendly** sources of protein. The **constraint to global consumption growth** is expected to be on the supply of **whole fish.**
- The earth consists of 70% water, but **only 2%** of our food is **from the ocean,** and **aquaculture could be an alternative** to satisfy the increased demand for fish proteins
- In 2011, farmed fish production overtook beef production. By 2023, it is expected that **fish for human consumption from aquaculture will exceed wild catch.**

*Notes: *E = estimate*

Sources: OECD – FAO Agricultural Outlook 2013–2022, FAO (2016), Kontali, PwC Seafood, Earth Policy Institute (2013), OECD

Fish feed volumes are expected to continue to grow at ~3.6% per year driven by growth in the aquaculture industry

Global aquaculture feed market by species (2010-2020E,[1] million tonnes)



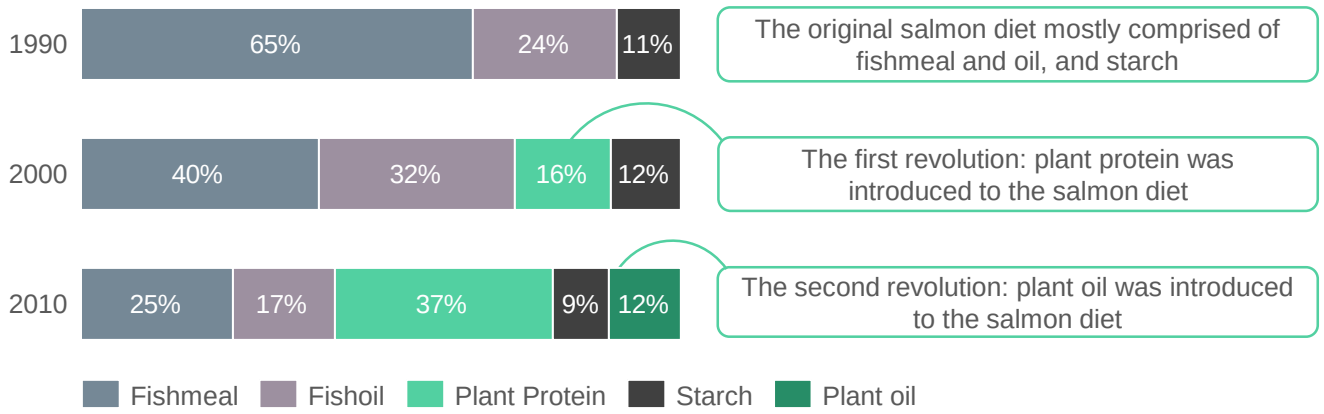
Segment	CAGR[2] 10-14	CAGR[2] 14-20E[1]	Driver
Other	9%	3.3%	Growth primarily driven by demand for catfish as food
Sea bass and Sea Bream	5.5%	2.9%	Rising export of fish to Americas – European economies displaying continued slow growth
Shrimp	6.9%	3.8%	Relatively strong demand in emerging markets is driving expected growth
Salmonids[3]	8.7%	2.0%	Strict regulations cap growth potential
Tilapia	10.6%	5.3%	Relatively strong demand side in emerging markets is driving expected growth

Notes: 1. E = estimate, 2. compound annual growth rate, 3. Salmonids = include salmon, trout and char

Sources: FAO, World Bank, Frost & Sullivan, Nutreco, Global Markets Insight, Springer Science & Business Media, PwC interviews

The feed industry is facing the challenge of substituting marine and agricultural ingredients with novel ones

Change in aquaculture diet composition by weight in Norwegian aquaculture



The third revolution: the introduction of novel ingredients like algae and bacteria

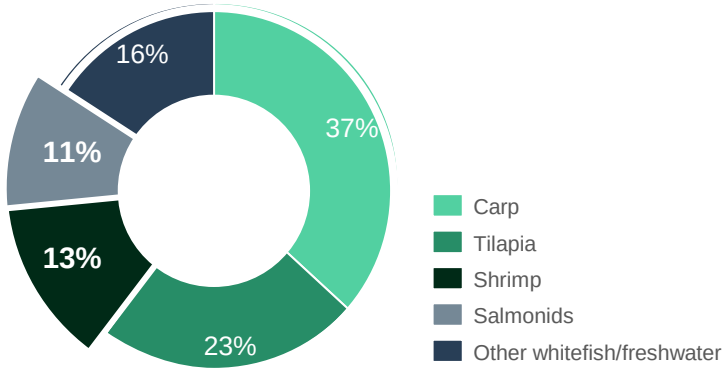
- Access to **sustainable feed ingredients** is one of today's **main challenges** for sustainable growth within aquaculture.
- The use of fishmeal and fish oil from wild catch is a challenge as they have a **static supply and only 14% of fish caught for all uses were MSC-certified in 2017.**
- The increased usage of agricultural ingredients to offset dependence on fishmeal is also problematic due to the **clearing of land for production** of soy and rapeseed. The industry is facing a catch-22.
- **There have been three revolutions within fish feed. First, the introduction of plant protein. Second, the introduction of plant oil, and today, micro algae and bacteria, among others, to meet the need for marine omega-3 without being dependent on fisheries.**

- **Marine ingredient content has been reduced over time. Its role is now strategic rather than to provide bulk protein or oil.**
- **Due to fishmeal and oil's critical components, like functionality and mix of amino acids, they are now at a level that is very hard to reduce further (without novel ingredients).**
- **Depending on the alternatives used, their substitution by other ingredients may affect the health of farmed fish. Vegetable ingredient-based diets can affect the intestinal flora and immune defenses and overall health status of the fish. Too little omega-3 can make salmon less robust and more prone to develop viral diseases.**
- **To offset their rising prices, as feed tonnages increase, feed companies will continue to stretch available quantities of fishmeal and fish oil further by substituting them with other ingredients. Those novel ingredient are not yet scalable.**
- **An increase in the amount of available offcuts and trimmings** from whole fish processing might be possible through new ways of collecting or processing. There are offcuts which are presently not made into fish meal and oil.

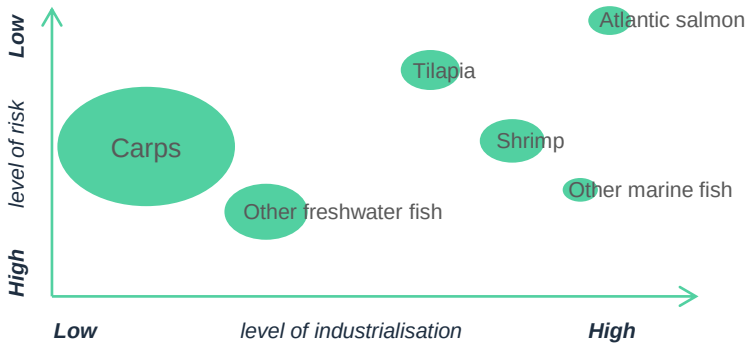
Photo: Skretting
Sources: NOFIMA, SEA at Risk, FAO 2016 SOFIA report, Seafish (2016), IntraFish (2017, 2018)

We expect the largest transformation for shrimp and salmonid feed as farmed shrimp and salmon are highly valued, industrialised, and globally traded species

Global production of aqua feed in 2016 (39.9 million tonnes)



Level of risk and industrialisation of species



- **In 2016, 39.9 million tonnes of aqua feed was produced globally, whereas salmon feed represented ~4.4 million tonnes, and shrimp feed ~5.2 million tonnes.**
- **The fishmeal trap**: "is the hypothesis that aquaculture is environmentally degrading because increased demand for feed leads to increased fishing for wild species used to produce feed, thereby threatening the viability of wild fish stocks, and that growth in aquaculture production will be limited by availability of wild fish used as feed in aquaculture production."
- Carnivorous species, like **salmon** and **sea bass**, are most **exposed to the fishmeal trap** as they use the highest share of marine inputs in feed. Some omni- or herbivorous species, like tilapia, pangasius and shrimp, are also exposed as fishmeal is used to increase growth rate.
- **Carp,** a low-value species, is farmed **relatively sustainably** as they grow on rice paddies and feed on grass, plankton and detritus boosting rice yields and producing little pollution.
- **Tilapia**, a medium-value species, is produced mainly in **Asia** and **Latin America**. These regions absorb much of their own domestic production as it is an affordable source of protein.
- **High-value species, salmon and shrimp, play a more significant role in international trade. Although salmon and shrimp are relatively small in volume compared to other species, they are very visible products in many markets due to a high level of industrialisation and high R&D and innovation activities.**
- Global feed producers, like Skretting, have for years developed **feed and feed technologies** for salmon, like MicroBalance, which can be **adopted for other species.**
- **As salmon and shrimp are exposed to the fishmeal trap, and more highly-valued, industrialised, and internationally traded, and thereby more visible products, we expect the largest transformation for salmonid and shrimp feed in the short to medium-term.**
- **As global feed producers are diversifying into low-value species, and technology transfer from salmon to other species is likely to occur, we expect transformation for species like carp in the medium to long-term.**

Notes: figures adapted from Marine Harvest Industry Handbook 2017

Sources: Fishbase,org, FAO, OECD, Marine Harvest Industry Handbook (2017), Naylor et al.. 2000, Skretting, Professor Frank Asche - Green Growth in Fisheries and Aquaculture Production and Trade

The US represents the most promising consumer market for farmed salmon, where Walmart is the largest player

About 85% of Norwegian salmon and trout are processed abroad in countries such as Poland, Denmark and the Netherlands, mostly due to cheaper labour costs and favourable EU tariff regulations. They are also closer to end-markets. The largest processing company, Morpol, is owned by Marine Harvest and is located in Poland. Seafood giant, Lerøy, also owns processing companies in the Netherlands, Sweden and Norway. MerAlliance, another large processor located in France, is owned by Thai Union, one of the largest seafood companies in the world. The top five companies process about 190,000 tonnes of salmon (head on gutted) every year, and the final product is, among other things, smoked salmon.

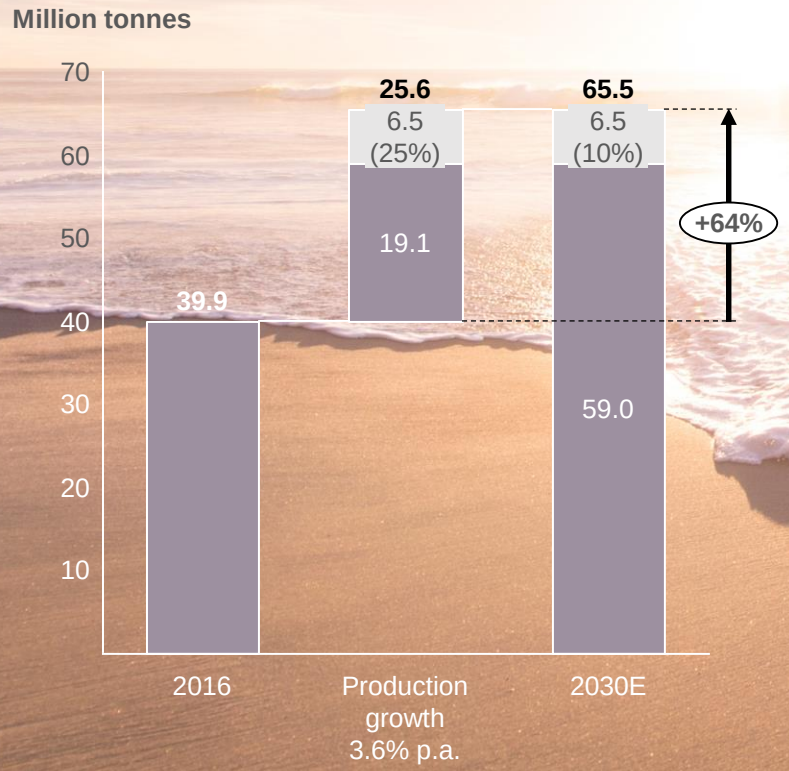
The US is by far the largest consumer market for salmon, thereafter France, Germany, the UK and Brazil, with a total consumption of 1.07 million tonnes (whole fish equivalent). Walmart is retail market leader in the US, E. Leclerc in France, Edeka in Germany, Tesco in the UK and Carrefour in Brazil. Per capita consumption, however, varies.

*Notes: *head on gutted, **whole fish equivalent*

Sources: IntraFish 150, Kontali salmon world (2017), Ilaks (2017), Statista, Marine Harvest Industry Handbook (2017), Marine Harvest Annual Report (2017), Norwegian Seafood Council

In 2030, 6.5m tonnes of the global aqua feed production must be transformed in order to reach the 10% goal

Global aqua feed production in 2016 and estimated production in 2030 (million tonnes)



In 2030, the global, estimated production of aqua feed will increase to **65.5 million tonnes**, following the aquaculture growth rate of 3.6% p.a. This equals a **total growth of 64%.**

In order to transform 10% of the aqua feed value chain, **6.5 million tonnes** must be sustainably produced in 2030.

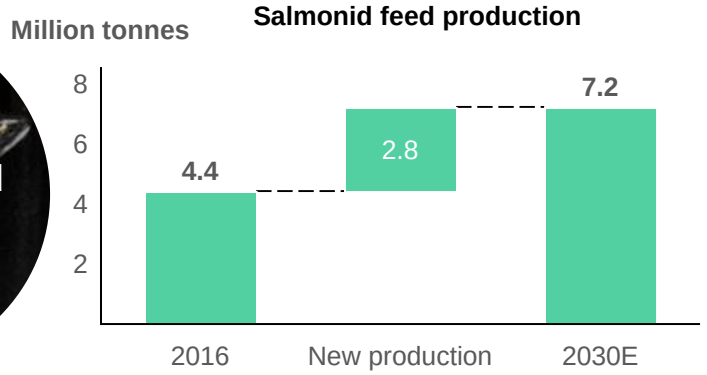
For the transformation to only be covered by production growth, **25% of new production** (6.5m tonnes) must be covered by sustainable ingredients or technology.

Notes: E = estimate

Sources: PwC Analysis, PwC Strategy& (2017) Global fishmeal and oil market

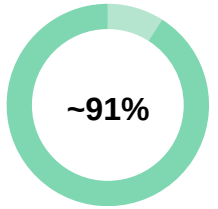
If salmon and shrimp feed drive transformation change, 41% of their combined production in 2030 will cover the goal of 6.5 million tonnes

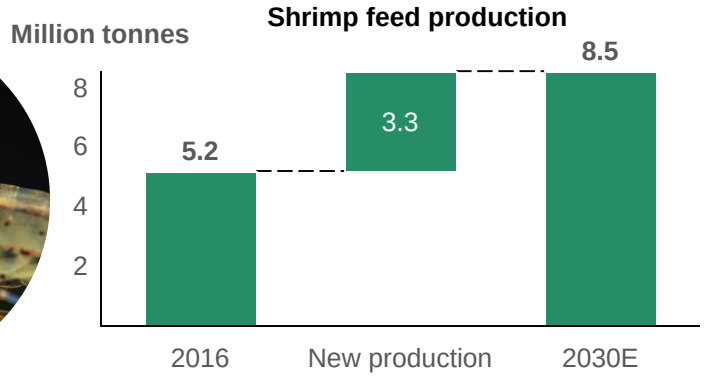
We expect feed for salmon and shrimp to be the main contributors to the value chain transformation. Assuming the annual growth rate to be 3.6% p.a. and the share of feed for salmonids and shrimp to be constant at **11% and 13% respectively**, we expect the global production of salmon and shrimp feed in 2030 to be **15.7 million tonnes in total.**



Salmonid feed, 2030

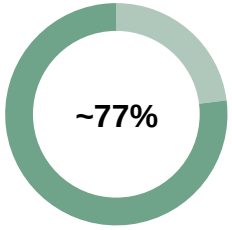
For the salmonid feed value chain to cover the transformation goal of 6.5m tonnes**, 91% of the total value chain of 7.2m tonnes** needs to be produced sustainably in 2030.





Shrimp feed, 2030

Similarly, **77% of the total shrimp feed value chain of 8.5m tonnes** needs to be produced sustainably in 2030 in order to reach the transition goal of 6.5m tonnes.

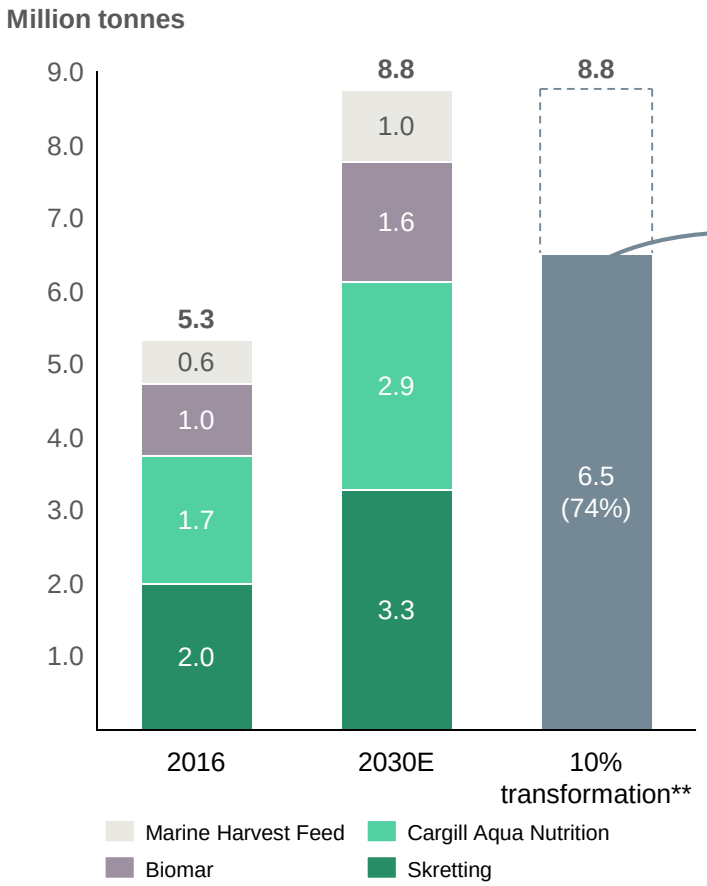


Notes: E = estimate

Sources: Marine Harvest Industry Handbook 2017, Kontali, FAO, PwC Analysis

If the big four feed companies take responsibility for the 10% transformation of global aqua feed, they must transform 74% of their feed by 2030

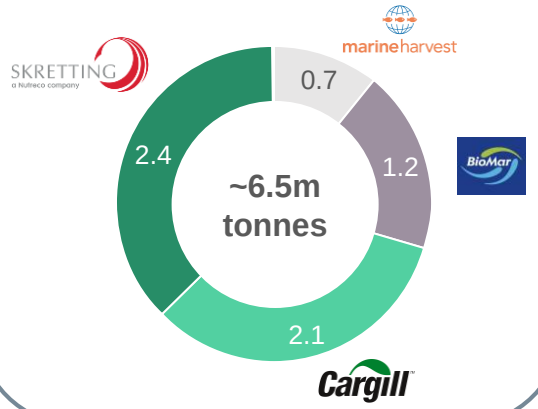
Total feed production Skretting, Cargill Aqua Nutrition, Biomar and Marine Harvest Feed in 2016 and 2030E (million tonnes)



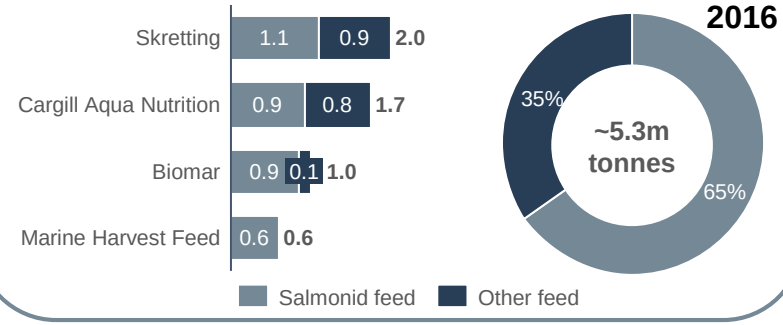
Today, the big four feed companies produce 5.3m tonnes in total. Assuming constant market shares and an annual growth rate of 3.6%, the four producers will have a total production of **8.8m tonnes** in 2030.

For the transformation of **6.5 million tonnes to be covered by the big four feed companies**, Skretting, Cargill Aqua Nutrition, Biomar and Marine Harvest Feed, **74%** of their combined production needs to be transformed.

For each player, transforming 74% of the production equals (in million tonnes):

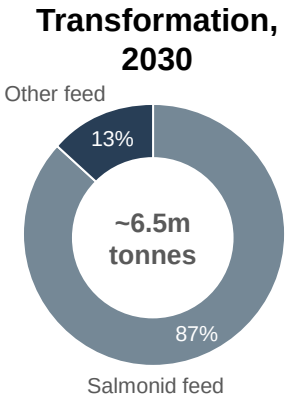


In 2016, the share of **salmonid feed** varies between the companies, but in terms of total production, it represents **65%** of the big four companies' combined feed production:



In 2030, the total **salmonid feed** production from these companies will have increased to 5.7m tonnes, assuming an annual growth rate of 3.6% and a constant share of salmonid feed production.

If all salmonid feed production from Skretting, Cargill Aqua Nutrition, Biomar and Marine Harvest Feed is produced sustainably in 2030, one would cover **87%** of the transformation goal of 6.5m tonnes.

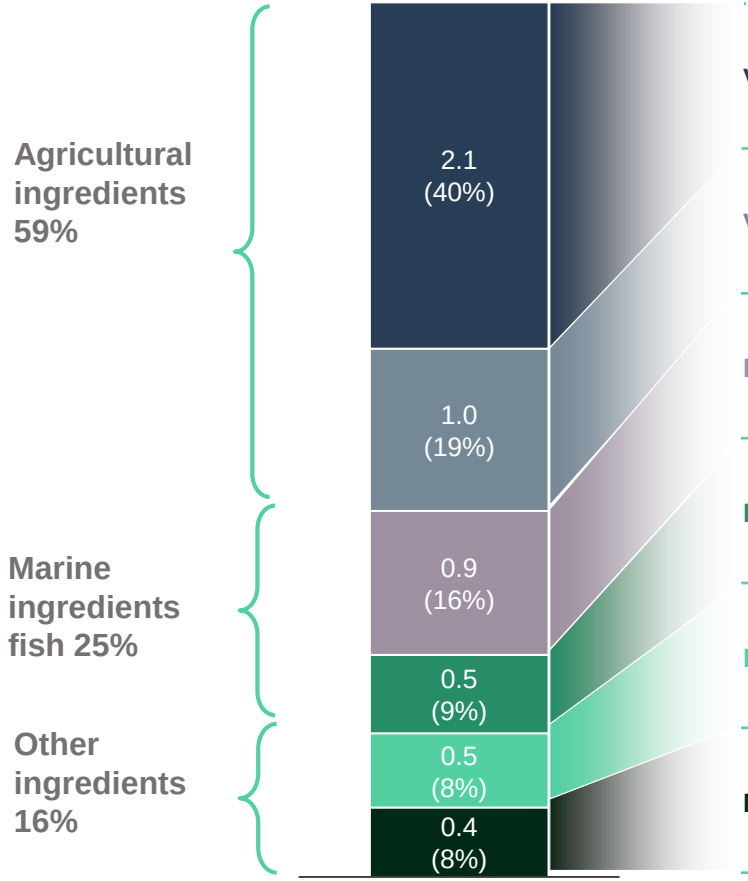


**Assuming 3.6% growth p.a. and constant market share, E = estimate, **10% transformation (6.5m tonnes) of global aqua feed equals 74% of the big four' feed production in 2030*

Sources: Skretting Sustainability Report 2016, Cargill Aqua Nutrition Sustainability Report 2016, Biomar Sustainability Report 2016, Marine Harvest Annual Report 2016, IntraFish

Agricultural ingredients represent 59%, and marine ingredients 25%, of the big four feed companies' feed

Big four feed companies' ingredients in 2016 combined, in million tonnes and weighted average in %



Challenges for the whole industry

The increased usage of agricultural ingredients to offset dependence on fishmeal is problematic due to the **clearing of land for production** of soy and rapeseed. The heavy use of chemicals has led to soil degradation and water contamination. **The rainforest has been destroyed for soy plantations.**

The use of fishmeal and fish oil from wild catch is a challenge as they have a **static supply and only 14% of fish caught for all uses were MSC-certified in 2017.**

Notes: Weighted average percentage. See appendix for calculations.

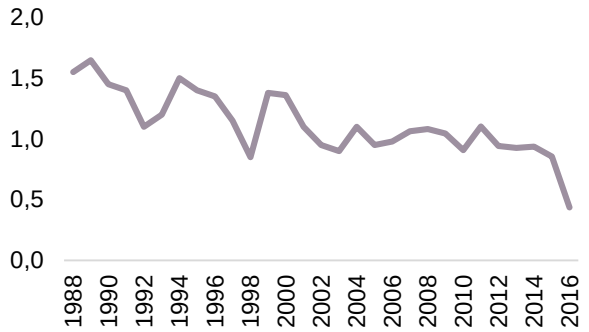
Sources: Skretting Sustainability Report 2017, Cargill Aqua Nutrition Sustainability Report 2016, Biomar Sustainability Report 2016, Marine Harvest Annual Report 2016, Nofima (2011)

The big four consume 60% of available fish oil, and unless they change production strategy they will demand close to 100% in 2030

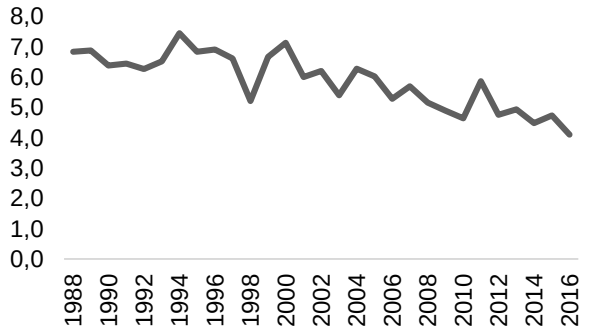
Available supply 2015	Big four usage 2016*	Expected big four usage 2030*
Fish oil 0.8m tonnes	**~0.5m tonnes** Equalling 60% of available fish oil, assuming static supply of 0.8m tonnes	**~0.8m tonnes** Equalling 98% of available fish oil, assuming static supply of 0.8m tonnes
Fishmeal 4.7m tonnes	**~0.9m tonnes** Equalling 19% of available fishmeal, assuming static supply of 4.7m tonnes	**~1.5m tonnes** Equalling 31% of available fishmeal, assuming static supply of 4.7m tonnes

Historical development of fish oil and fishmeal supply 1988-2016

Global fish oil production (million tonnes)



Global fishmeal production (million tones)



Fish oil is a scare resource with **decreasing supply.** We expect static supply in the future as total allowable catch highly depends on quotas and environmental phenomena like El Niño.

In 2016, the big four feed companies used **60% of global available fish oil**, equalling 0.5 million tonnes of total global fish oil used in the aquaculture industry.

Assuming an annual feed growth rate of 3.6% and a constant share of fish oil in feed, the total use of fish oil by Skretting, Cargill Aqua Nutrition, Biomar and Marine Harvest Feed will be **98% of available resources in 2030.**

Fishmeal has **decreasing supply,** but is **not as scarce as fish oil** as there are more volumes available. However, availability depends on the same external factors as fish oil as fish oil is a by-product of fishmeal.

Today, the big four feed companies consume **19% of global available fishmeal**. With a growth rate of 3.6% per year, consumption will only account for 31% of total supply in 2030.

*Notes: *Assuming growth rate of 3.6% p.a., and constant market share for Skretting, Cargill Aqua Nutrition, Marine Harvest Feed and Biomar and constant share of fish oil and fishmeal in production*

Source: PwC Analysis, Strategy& 2017 – Global fismeal and oil market outlook

Algae oil could potentially replace fish oil due to its high omega-3 content

Potential substitutes to fish oil

	Description	Category	Pros & Cons	Sustainability and other concerns
Fish oil **Can be substituted by:**	Oils derived from the tissues of oily fish.	1	✓ High Omega-3 oil content ✓ Significant volume available ✘ Expensive	✓ Consumers might be willing to pay more for seafood with high levels of omega-3 ✓ Most fish oil producers are MSC-certified or in Fisheries Improvement Plans (FIP), with the exception of Southeast Asia ✘ A scare resource, bycatch, illegal fishing and related social issues
Palm oil	Oils derived from palm trees.	2	✘ No DHA/EPA content ✓ Significant volume available ✓ Cheap	✓ Positive for feed utilisation and as a pellet binder ✓ Produces more oil per hectare than many other oil crops ✘ Concerns related to deforestation and GHG - not accepted by consumers ✘ Higher risk, negative impact on biodiversity even if RSPO-certified (Indonesia)
Hydrogenated vegetable oil	Oils derived from various oily vegetables to which hydrogen is added to improve the solidity (soy, rapeseed).	3	✘ No Omega-3 oil content ✓ Significant volume available ✓ Cheap	✓ Rapeseed contains about the same crude protein level as fishmeal ✘ Concerns related to deforestation and destruction of habitat ✘ Produce more greenhouse gas emissions than fossil fuels once emissions from indirect land use change are taken into account (differences between regions)
Krill oil	Oils derived from small sea crustacean widely dispersed across the world's oceans.	4	✓ High Omega-3 oil content ✘ Insignificant volume harvested ✘ Very expensive	✓ Willingness to pay if sourced sustainably. ~30% more expensive than fishmeal. ✘ Criticised for operating close to penguin colonies and whale feeding grounds ✘ About 1% of krill biomass is harvested. Aker Biomarine supplies ~60% (~158,000 tonnes) of harvested krill, and has an exclusivity agreement with Biomar.
Algae based oils	Oils extracted from macro and micro-algae.	5	✓ High Omega-3 oil content ✘ Insignificant volume available ✘ Very expensive	✓ Considered by the industry to be the most viable novel alternative to fish oil ✓ Algae oil is three times as concentrated as fish oil - 1% can replace 3% of fish oil ✘ The challenge is to get buy-in from farmers to scale up production ✘ Care must be taken regarding nutrient concentration and digestibility - may contain toxins. Not all species are suitable in feed.
GM-canola and camelina oil	Omega-3 camelina oil and canola and oil extracted from rape plants that have been genetically modified to produce the key fatty acid DHA.	6	✓ High Omega-3 oil content ✓ Will be available in Chile and Canada (high volumes expected) ✓ Competitively priced	✓ Various reports conclude that GM commodities approved by the EU are safe ✓ Research by Cargill and Nofima show promising results in salmon ✘ Strong resistance towards GMOs in agriculture and consumer food products in Europe - Europe has the world's strictest approval system for GMOs ✘ Many countries have banned the production, transport, and sales of GM canola

Sources: Nofima 2011, The Fish Site (2017), IntraFish 2016, Feed-X interviews, Ecologist 2012, Strategy& / PwC interviews, Technavio 2017, WWF (2016)

✘ = negative ✓ = positive ? = unknown

Bacterial proteins could be an alternative to fishmeal if produced sustainably

	Description	Category	Pros & Cons	Sustainability and other concerns
Fishmeal **Can be substituted by:**	Meals derived from whole fish and inedible by-products of fish.	7	✓ High protein content ✓ Significant volume available ✗ Expensive	✗ Anti-oxidants used to reduce flammability have recently been identified as toxic and they are passed through the food chain on to human consumption ✗ Fishmeal made mainly from by-product usually has a slightly lower protein content, a higher mineral content, a higher ash content and more problems with traceability, than meal made from whole fish
Corn and wheat gluten meals	Oils derived from maize and wheat plants.	8	✓ High protein content ✓ Significant volume available ✓ Cheap	✗ Concerns related to deforestation and soil erosion ✗ Concerns related to GMO-corn (Roundup Ready) and the development of resistant "superweeds," water use and increased pesticides usage on GM-crops ✗ Plants which could otherwise be used for human consumption
Soy meal	Meals derived from soy plants (not from concentrate or hydrolysates).	9	✗ Low protein content ✓ Significant volume available ✓ Cheap	✓ Has been used to replace fishmeal ✗ Concerns related to deforestation and destruction of habitat (Cerrado) ✗ Consumer skepticism in Europe (most soy is genetically modified)
Feather meal and poultry meal	Meals derived from animal by-products from poultry.	10	✓ High protein content ✓ Significant volume available ✓ Cheap	✓ Circular economy ✗ Despite the high protein share, feather meal is relatively cheaper than other protein meals, due to poor digestibility ✗ Prohibited in Europe due mad cow disease, consumer scepticism
Marine biotech hydrolysates	The breakdown of protein into smaller peptides and free amino acids through a hydrolysis process.	11	✓ High protein content ✗ Insignificant volume available (high investment costs, complex) ✗ Very expensive	✓ Circular economy ✗ Hydrolysis is a very complex process with high risks and investments costs. Most producers cannot scale up production enough for it to be a major input in feed. ✗ Fish protein hydrolysates (FPH) should be used higher in the food recovery hierarchy as food to humans
Microbial ingredients (bacteria, yeast, microalgae)	Microbial ingredients extracted from bacteria, yeast and microalgae.	12	✓ High protein content ✗ Insignificant volume available (not commercialised yet) ✗ Expensive	✓ Bacterial proteins show strong potential as alternatives to fishmeal ✗ Concerns related to methane from the fracking industry used as input in producing bacteria (Calysta)

Potential substitutes to fishmeal

Sources: Strategy& interviews, WWF, PwC report 2017

✗ = negative ✓ = positive ? = unknown

Insect proteins could be an alternative to fishmeal, but may lack acceptance by retailers

Potential substitutes to fishmeal

	Description	Category	Pros & Cons	Sustainability and other concerns
Mesopelagic fisheries	Oils and meals derived from the tissues of fish living in the inter-mediate pelagic water masses between the euphoric zone.	13	✓ High Omega-3 oil content ✘ Uncertainty regarding volumes (not exploited yet) ✘ Very expensive (costly to harvest)	✓ A large unexploited biomass of mesopelagic fish living in the deep ocean. This biomass has recently been estimated to be 10 billion metric tons, however, the real biomass is still in question. ✘ We lack a holistic assessment of the community and an understanding of the mechanisms controlling this biomass ✘ Unknown impacts on climate, and is a finite resource
Insect meal	Meals derived from various insects.	14	✓ High protein content ✘ Insignificant volume available (not commercialised yet) ✘ Expensive	✓ Promising research by Nifes shows that insect meal can replace fishmeal ✓ Circular economy: favorable nutrient content, and grows on animal manure or waste and therefore has a direct conversion of waste to valuable nutrients ✘ Insect-based proteins categorised as animal by-product (PAP)* in the EU poses a threat as retailers and consumers are sceptical about land-animal protein in fish
Guar and gum meal	Guar gum, also called guaran, is a substance made from guar beans.	15	✓ Moderate protein content ✓ Significant volume available ✓ Cheap	✘ Water use, deforestation, about 90% of seeds used in fracking (oil & gas) ✓ Rich source of highly digestible protein ✓ Good amino acids profile ✓ A cost-reducing replacement for soybean meal, soybean concentrate and fishmeal
Salmon protein hydrolysates	Protein derived from salmon by-products through hydrolysis.	16	✓ Moderate protein content ✘ Insignificant volume available (high investment costs) ✘ Expensive	✓ Circular economy ✘ Fish protein hydrolysates (FPH) should be used higher in the food recovery hierarchy as food to humans ✘ Not accepted by the EU and consumers in Europe for use in salmon feed. However, if the protein is hydrolysed to the extent that the origin is of no importance, it could potentially be used.
Marine bristle worms and invertebrate animals	Proteins derived from tunicates (marine invertebrate animals) and polychaete (marine bristle worms).	17	✓ Moderate to high protein content ✘ Insignificant volume available ? Price unknown	✓ Circular economy (bristle worms feed on silage, tunicates on plankton on nets, ropes, hard surfaces, etc.) ✘ Tunicates contain 90-95% water, therefore large volumes are needed ? Sustainable production and harvesting practices

*Notes: *PAP – Processed Animal Protein*

Sources: Fishfarming expert 2017, Nifes 2011, Frontiers in Marine Science (2016), PwC interviews, Sustainable Business Toolkit, UniResearch, AgriMare Bio

✘ = negative ✓ = positive ? = unknown

The four main feed producers are investing or/and researching microalgae as feed ingredient

Less DHA & EPA in farmed salmon

Fatty acid composition of farmed salmon has changed due to the use of plant protein and oils in fish feed at the expense of fishmeal and oil.

According to NIFES, the content of EPA and DHA in Norwegian farmed salmon fillets has decreased by 58% between 2005 and 2015.

According to Giovanni Turchini, Professor at Deakin University in Australia and expert in nutrition, food quality and fish oil: “even if there is less omega-3 in farmed salmon than 10-20 years ago, farmed salmon is still one of the best sources of n-3LC-PUFA available to humans.”

Also, farmed fish contain less pollutants such as heavy metals, PCB[1] and dioxin-like compounds due to the reduced inclusion of fishmeal and fish oil.

	Strategy	Novel ingredients
SKRETTING a Nutreco company	The goal is not to reduce the use of marine ingredients to zero, but to reduce the dependence on it to zero. In order to offer flexibility they have a range of ingredients that can be used alternatively depending on availability. Can completely replace fishmeal.	✓ Microalgae to replace fish oil (Veramaris: Royal DSM and Evonik) heterotrophic fermentation using sugar as input ✓ Using calanus finmarchicus hydrosylate (marine zooplankton) from Calanus ✓ Insect research ✓ Camelina oil (omega-3) from Canada, Russia and Spain to replace fish oil and rapeseed oil
Cargill	Joint ventures and purchasing stakes in companies	✓ GM-canola oil to replace fish oil (BASF) ✓ Microbial protein from methane replacing fishmeal and soy (Calysta) ✓ Microalgae project (Mongstad) using photosynthesis ✓ Microalgae project using heterotrophic fermentation ✓ Insect research project Aquafly (Nifes and Protix) to replace fishmeal ✓ Research on tunicates (TuniChor AS)
BioMar	Collaborations and exclusivity agreements	✓ Krill oil (exclusivity agreement with Aker Biomarine) ✓ Microalgae protein and omega-3, AlgaPrime, heterotrophic fermentation (Bunge, Lerøy and Corbion Biotech) ✓ Yeast probiotic ingredient BACTOCELL® (Lallemand Animal Nutrition) only probiotic ingredient approved by the EU authorities for the use in fish feed
marineharvest	Feed and feed ingredients as part of branding and communication strategy (to consumer)	✓ Microalgae project (Mongstad) using photosynthesis

Notes: 1 polychlorinated biphenyls (industrial products or chemicals)

Sources: IntraFish, Skretting Sustainability Report (2016) PwC Analysis

The success of GMO-oilseeds, single cell & microalgae oils as marine substitutes is highly dependent on fishmeal and oil prices, and consumer acceptance

According to Calysta, their FeedKind protein requires **no agricultural land**, **a fraction of the fresh water required** by traditional agricultural products, and it **does not compete with the human food chain.** It can be a complete fishmeal replacement for species like salmon, trout and shrimp. The downside is that it uses methane from fracking as energy.

According to Mads Martinsen, Marketing Director at Skretting, the price curve for fish oil is historically rising due to increased demand. **Suddenly algae can outperform fish oil**. It is two to three times as concentrated as fish oil, and smaller quantities of algae oil is therefore needed in fish.

According to Giovanni Turchini, Professor at Deakin University in Australia: "there are other oils which contain EPA and DHA, but these **are not available in sufficient quantity and/or are still too expensive**. These "new oils" include krill oil, copepod oil and oils from fishery byproducts, but the only ones being produced in decent amounts and with growth potential are **genetically modified oilseed crops, and single-cell or micro-algae oils."**

According to Gorjan Nikolik, Senior Analyst at Rabobank, the development of novel ingredients like algae, bacterial protein and insects, **depends on the fishmeal price**. The price in 2017, of around $1,200 per tonne, is too low. **If prices rise** to $2,000 per tonne, **we'll see many of these alternatives come in.**

According to Andrew Mallison, Director General at IFFO, **"substitutes are needed because of the volumes** but not because fishmeal and fish oil are unsustainable. Aquaculture needs as many choices as possible. **Marine ingredients are the foundation of aquaculture.** So far, there's nothing better out there."

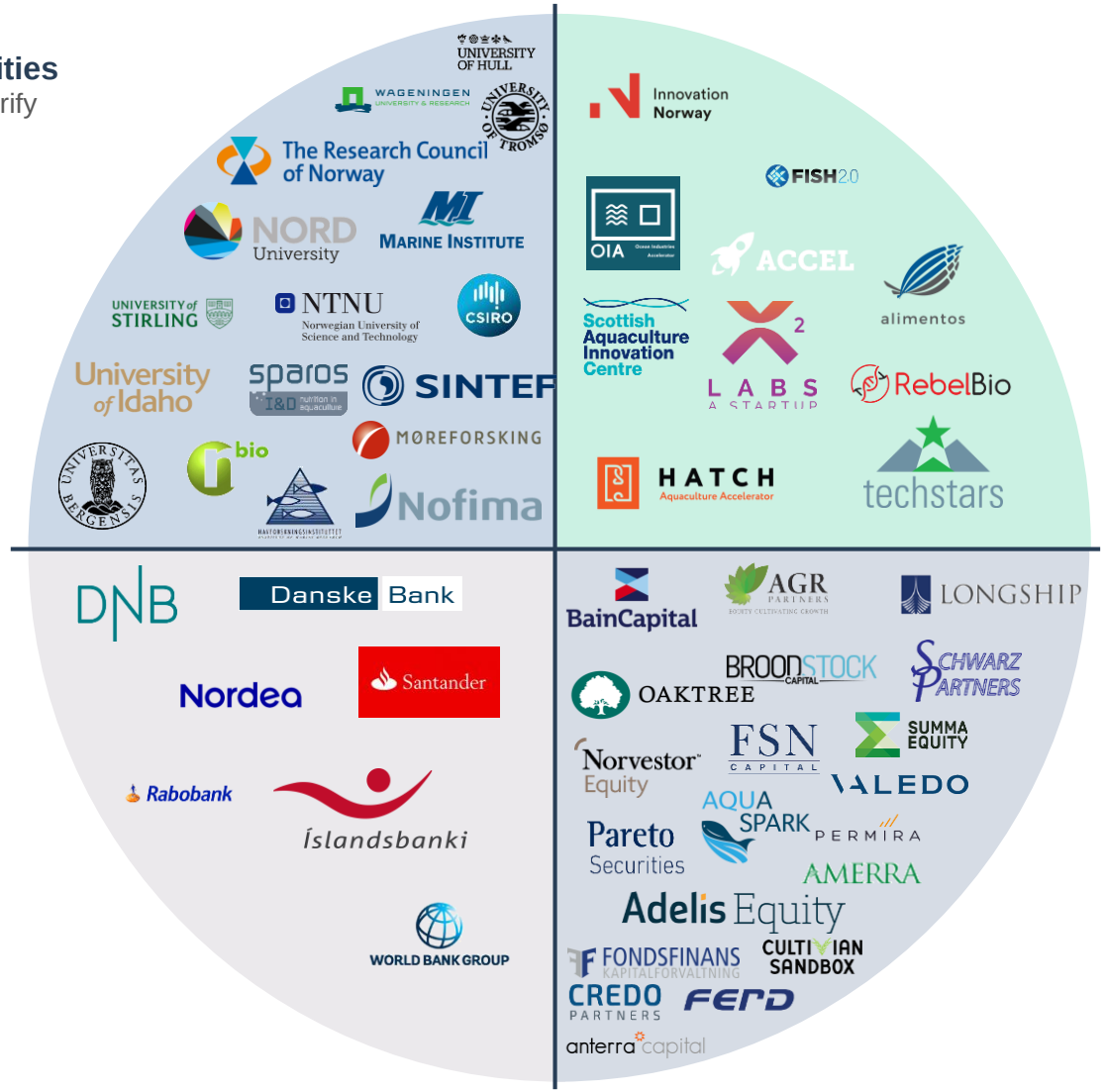
Feed producers are making progress on the development of vegetable oils from camelina, colza, rapeseed and canola that are **genetically modified to contain long chain fatty acids.** According to Alex Obach, Managing Director of Skretting Aquaculture Research Center: "this is a very interesting development and it works, but the **GMO controversy**, especially in Europe, may slow down this process."

Sources: IntraFish, Calysta, Ilaks

The innovation ecosystem consists of a range of different players globally with a majority share in Norway

R&D organisations and Universities
- Researching activities to test and verify new solutions and technologies

Seed money and accelerators
- Creating value by stimulating to profitable business development
- Supporting companies in developing their competitive advantage and to enhance innovation
- Accelerator programs seeking to find, develop and scale new innovations and start-ups



Leverage financing
- Financial partners to the seafood industry offering services as financing and debt capital markets, investment services and M&A advising, cash management services, deposits, guarantees and trade finance and trade in currency, interest and commodity derivate

PE and other equity
- Contribution of capital to realise attractive growth opportunities
- Consolidate a fragmented and growing seafood industry
- Invest in new technology

Notes: not exhaustive
Sources: PwC Research

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