Declining marine ingredient inclusion levels and an hypothesised link with fish health in farmed Atlantic salmon

ISAAH 2018 – QASH Project workshop

Prince Edward Island 6th September 2018

Neil Auchterlonie, Technical Director

IFFO, The Marine Ingredients Organisation

ISAAH
CHARLOTTETOWN
PRINCE EDWARD ISLAND
2018

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Salmon farming development history

From 0 to > 2 million tonnes production volume p.a. in approximately 50 years

Ellis et al, (2016) Aquaculture 458 82–99

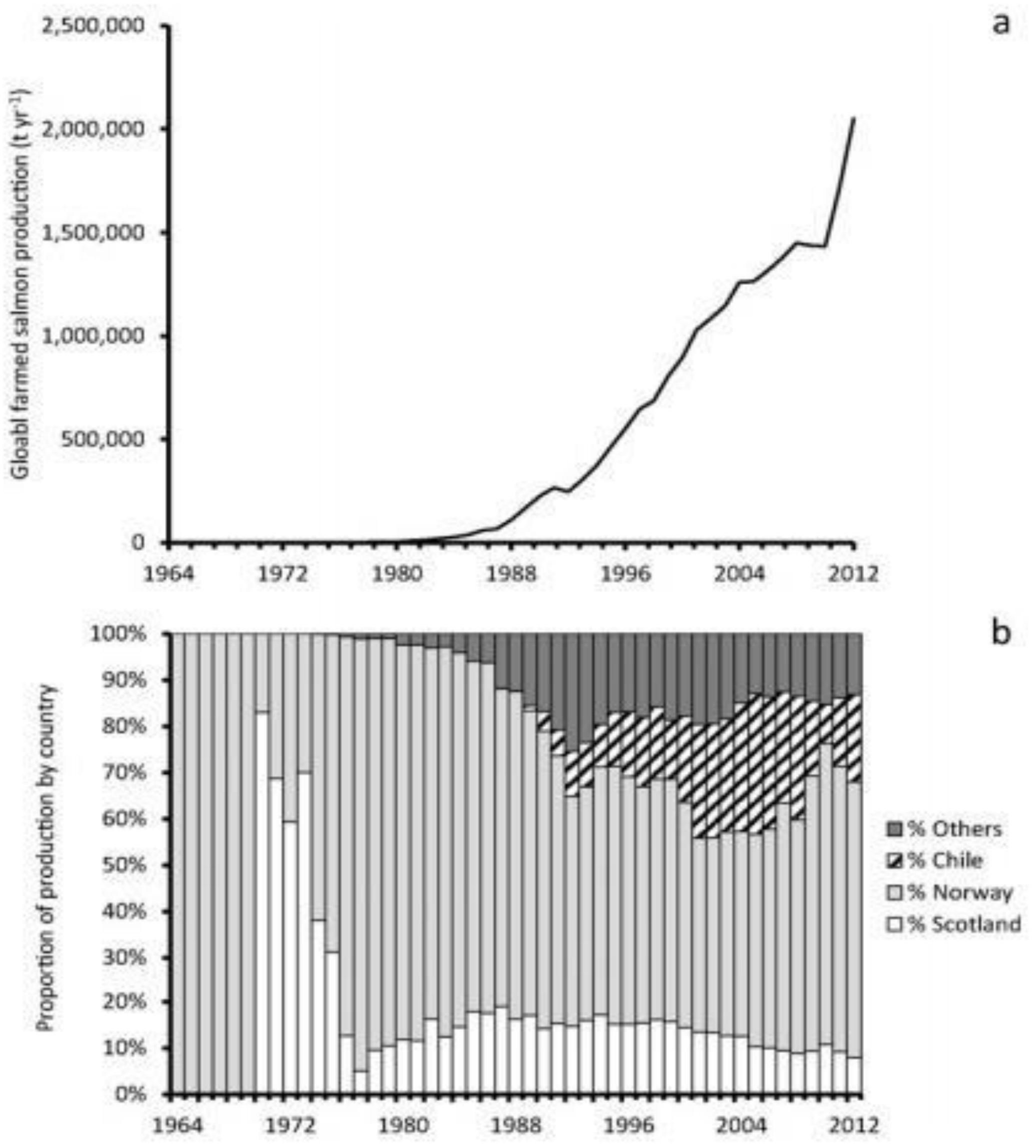

Fig. 1. Time series of global farmed Atlantic salmon production (data for 1950–2012 from http://data.fao.org (accessed 19/01/15) with nil production reported 1950–1963). a: harvest (t year^{-1}). b: Proportion contribution from Scotland, Norway, Chile and other countries (i.e. Canada, Faroe Islands, Australia, United States of America, Ireland, Russian Federation, France, Spain, Iceland, Sweden, Turkey and Denmark).

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How was this achieved?
Supported by innovation in:

Murray & Gubbins (2016) Marine Policy, 70, 93-100

Image: Salmar

Innovation in Feed:
Significant changes over time

- Very early (c.1900) diets minced animal flesh;
- Subsequent development of moist feeds around 1950s (e.g. Oregon Moist Pellet);
- Move towards dry feeds early 1960s (e.g. Abernathy Dry Diet) – improvements re biosecurity & pathogen risk;
- Fishmeal and fish oil (FMFO) became the mainstay of salmon feed from late 1960s onwards & increasingly through 1970s;
- 1980s, early 1990s salmon feeds mainly FMFO (90%) + binder;
- (partial) Substitution of FMFO related to supply and cost mid-1990s onwards;
- 2018: FMFO minority ingredients in salmon feed.

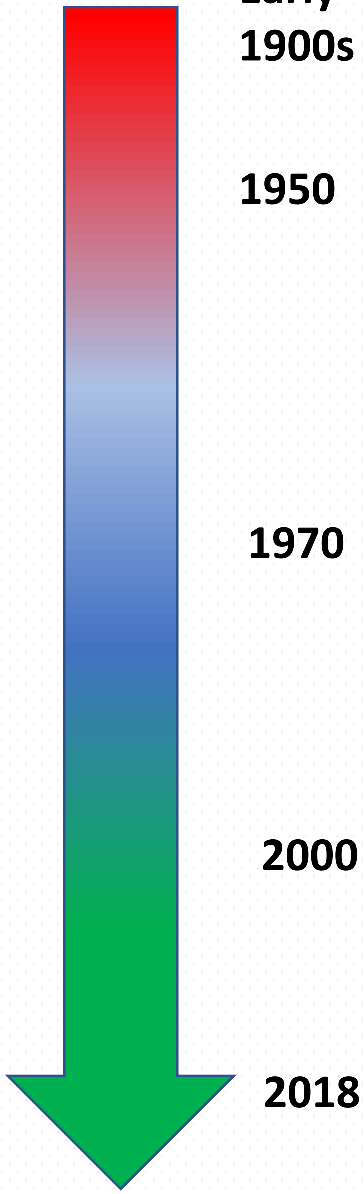
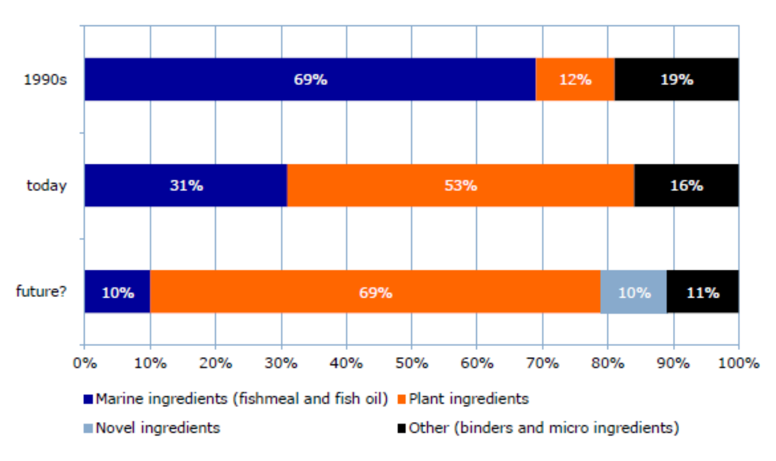


Figure 3: Salmon feed formula development, a gradual replacement of marine ingredients



Source: EWOS, 2015

Ingredient sources (% of the feed) 1990-2013

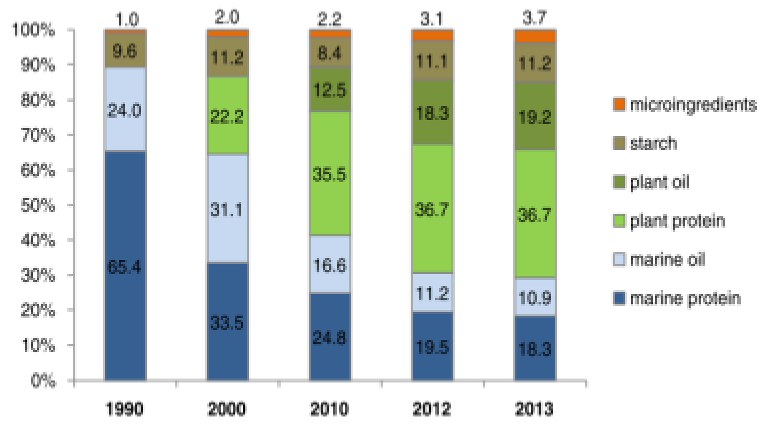


Fig. 1. Nutrient sources in Norwegian salmon farming from 1990 to 2013. Each ingredient type is shown as its percentage of the total diet.

Ytrestoyl, et al. (2015) Aquaculture 448 365–374
http://dx.doi.org/10.1016/j.aquaculture.2015.06.023

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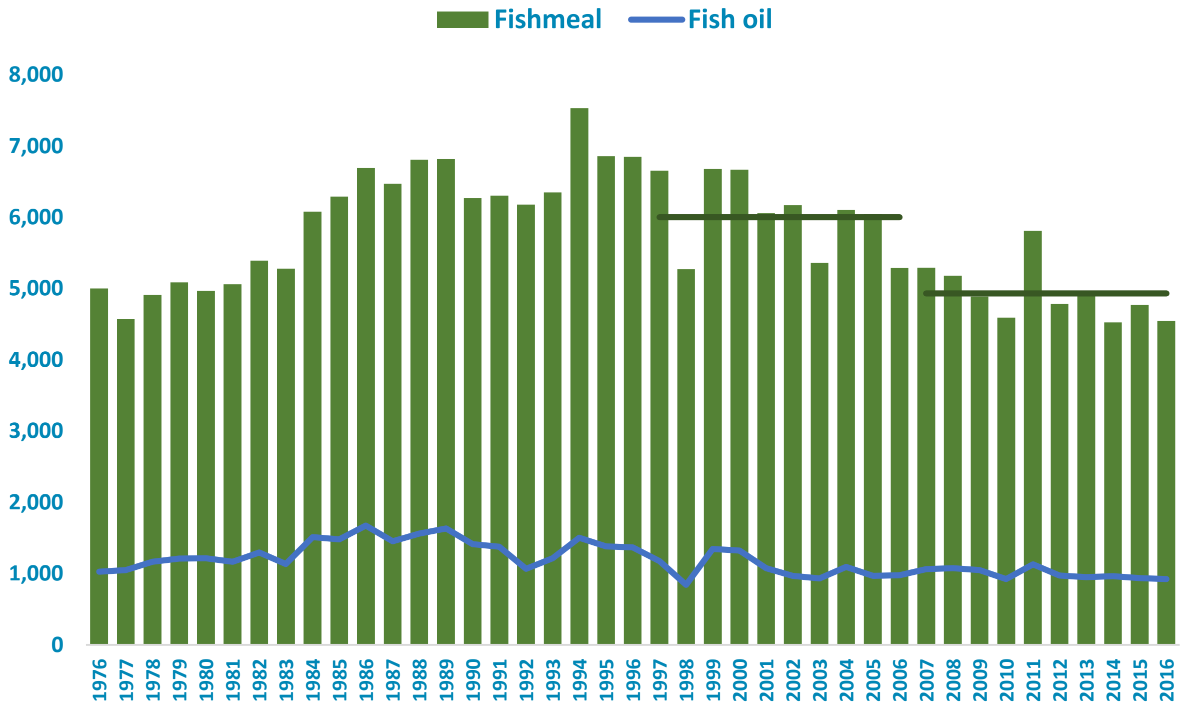
Partial Substitution: A response to the availability of FMFO....

World's fishmeal and fish oil supply (000 metric tonnes)



Source: IFFO

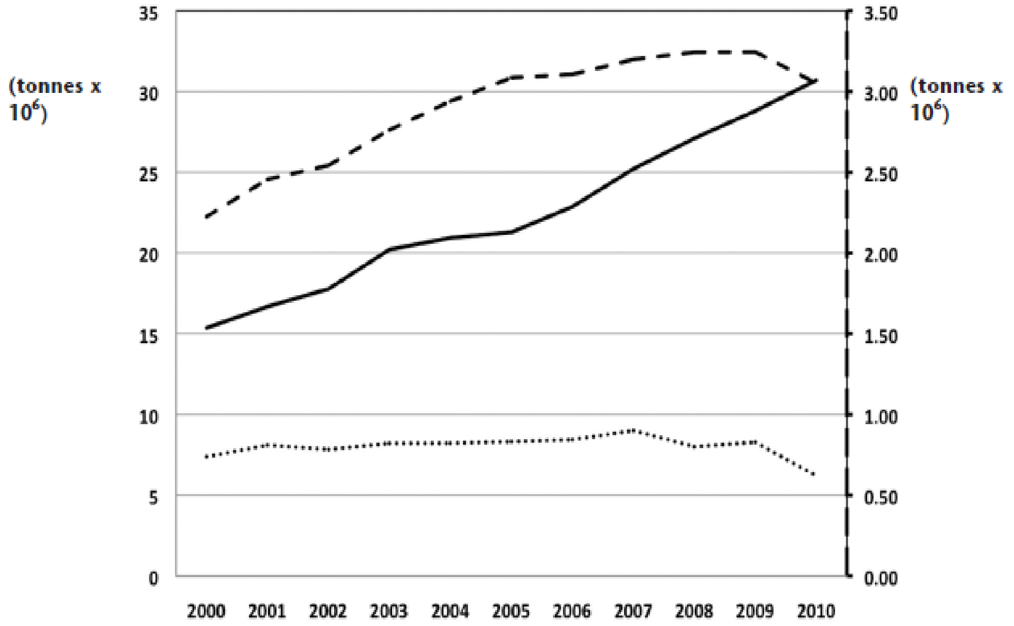


Figure 6. World fishmeal and fish oil consumption by aquaculture compared with growth in 'fed' aquaculture (millions of tonnes) during 2000-2010 (Solid line = Fed aquaculture; Broken line = Fish meal in aquaculture; Dotted line = Fish oil in aquaculture), (left hand vertical axis refers to fed aquaculture; right hand vertical axis refers to world fishmeal and fish oil consumption by fed aquaculture). (Shepherd & Jackson 2012, based on data from IFFO and FAO 2012a) (33,2)

Source: Shepherd, 2012

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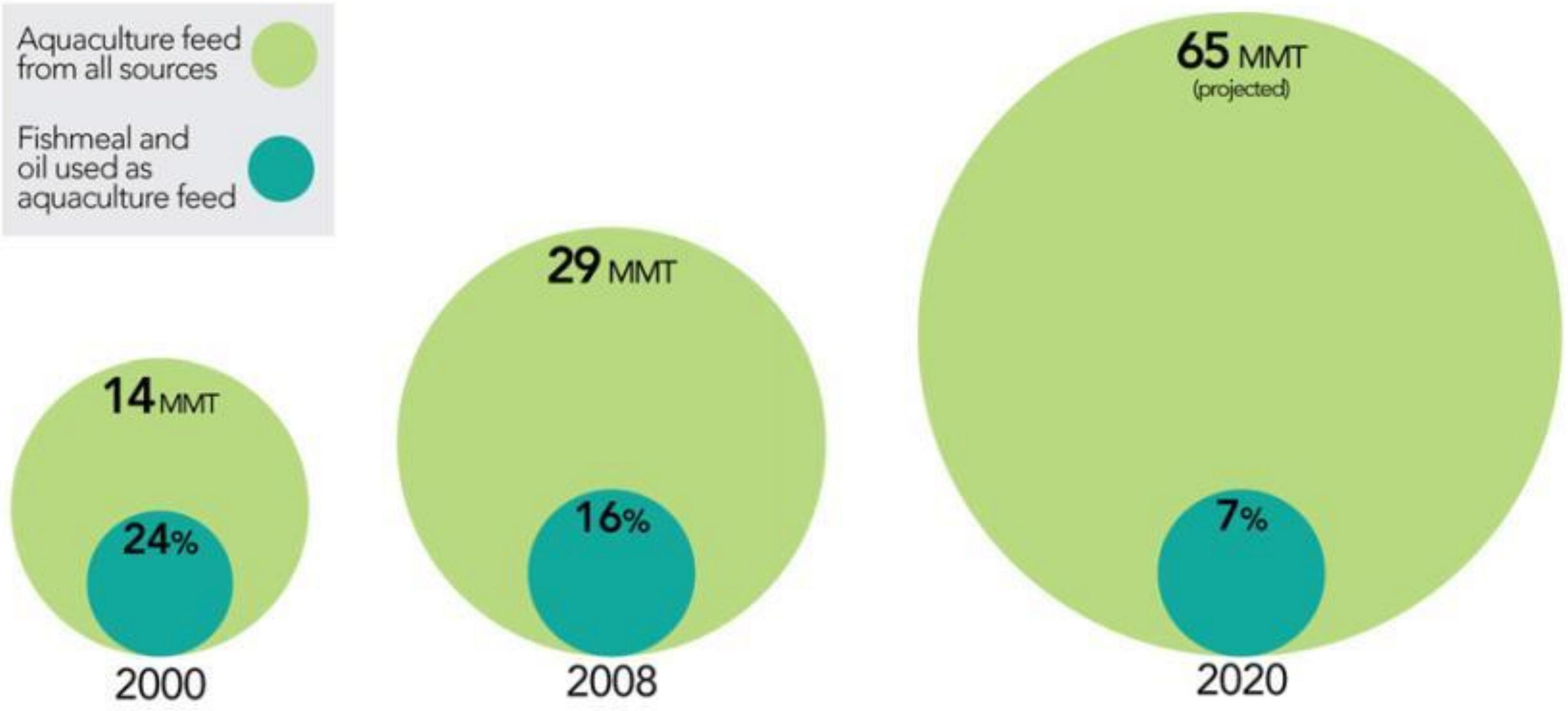
The Future – declining FMFO %age



This is a function of what FMFO is available annually vs. the growing volume of aquafeed globally.

FMFO volume will stay roughly similar YoY.

Source: Fry, J.P. et al., 2016. Environmental health impacts of feeding crops to farmed fish. *Environment International*, 91, pp.201–214. Available at: http://dx.doi.org/10.1016/j.envint.2016.02.022

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Atlantic salmon nutrition (in the wild)

Feeding of Atlantic salmon (*Salmo salar* L.) post-smolts in the Northeast Atlantic FREE

Monika Haugland, Jens Christian Holst, Marianne Holm, Lars Petter Hansen

ICES Journal of Marine Science, Volume 63, Issue 8, 1 January 2006, Pages 1488–1500,
https://doi.org/10.1016/j.icesjms.2006.06.004
Published: 01 November 2006 **Article history ▾**

Abstract

Stomach samples from 1384 Atlantic salmon, collected from 1991 to 2003 in the Northeast Atlantic, were analysed to fill the gap between studies on post-smolt diet in fjords and coastal areas of the Northeast Atlantic and studies on the diet of pre-adults and adults in the Norwegian Sea. The post-smolts fed largely on 0-group fish. Blue whiting was an important prey only in the slope current transporting the larvae from the spawning areas west of the United Kingdom into the North and Norwegian Seas. Sandeel and herring were important or present in the stomachs throughout most of the area studied. Unusually large quantities of 0-group herring in the Norwegian Sea in summer 2002 coincided with a high condition factor of post-smolts that year. The forage ratio of the post-smolts was positively related to the proportion of herring in the stomachs

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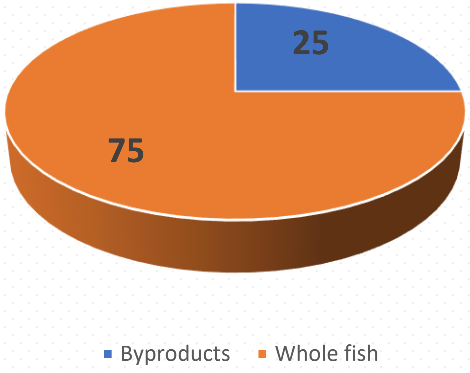
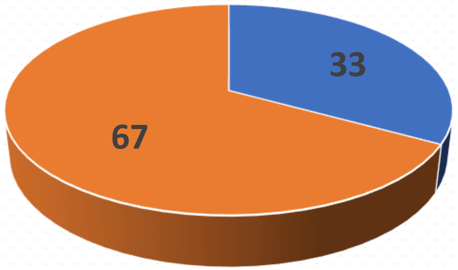
FMFO Raw Material Sources:

- Range of small pelagic fish species
- Includes sandeel, herring, blue whiting, Peruvian anchovy, menhaden
- Trend for increasing use of byproduct as raw material

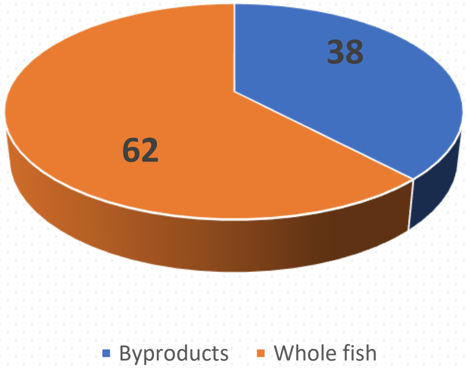
Estimated by Shepherd, 2012



Calculated by Newton, 2016



Predicted by FAO for 2025 (2016)



INDUSTRIAL GRADE FORAGE	Landings tonnes
Gulf menhaden (*Brevoortia patronus*)	479,000
Atlantic menhaden (*Brevoortia tyrannus*)	212,000
Sand-eel (*Ammodytes spp.*)	486,500
Total 1,175,000 tonnes of which 100% converted	
FOOD GRADE FORAGE	
Peruvian anchovy (*Engraulis ringens*)	8,468,000
Japanese anchovy (*Engraulis japonicus*)	1,567,000
South African anchovy (*Engraulis encrasicolus*)	228,000
Sprat (*Sprattus sprattus*)	262,000
Blue whiting (Micromesistius poutassou)	678,500
Capelin (*Mallotus villosus*)	958,500
Total 12,162,000 tonnes of which an estimated 90% was converted	
PRIME FOOD FISH	
Atlantic herring (*Clupea harengus*)	656,500
European sardine (*Sardina pilchardus*)	639,000
Chilean jack mackerel (*Trachurus murphyii*)	1,870,000
Japanese jack mackerel (*Trachurus japonicas*)	320,000
Chub mackerel (*Scomber japonicus*)	1,403,500
Californian sardine (*Sardina sagax caerulea*)	556,000
South African sardine (*Sardina sagax*)	263,000
Total 5,708,000 tonnes (average landings 2001 – 2006) of which an unknown percentage was converted	

after Wijkström, 2011

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Fishmeal as a feed ingredient:

(Hint: FM ≠ to other ingredients!)

Fishmeal

Raw material source: whole small pelagic species and byproduct (trimmings) from processed food fish

Crude Protein

- **High comparative Digestibility;**
- **Excellent essential amino acid balance (esp. methionine, lysine) compares favourably to carnivorous fish needs**

Energy

- **Energy dense (cal/g)**
- **Also contains fats (as FO) at c.8-12%**
- **Predominant energy substrate for carnivorous fish species**

Micronutrients

- **Rich in a range of micronutrients**
- **EFAs: Long chain n-3 fatty acids EPA & DHA**
- **Vitamins (esp. B-group, D)**
- **Minerals (Ca, Zn, Se)**
- **Other compounds may be important as well (e.g. TMAO, taurine, “compound X”)**

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Comparing other ingredients:

- Animal (e.g. poultry byproduct; blood meal; meat and bone meal)
- Plant (e.g. soymeal; wheat gluten)
- Novel (e.g. SCP; insect; algal oils)

    - With all these macronutrient requirements can easily be met, but nutritionally they are not equivalent
    - FM is nutritionally "rich" in comparison

Table 3. Percentage of essential amino acids (EAA)[1] in fishmeal (FM), rendered meat meal (MM), poultry by-product meal (PBM), blood meal (BM), soybean meal (SBM). Percentage of crude protein in the meal (in parenthesis).

Essential Amino Acid	FM (64.5%)[2]	MM (55.6%)[2]	PBM (59.7%)[2]	BM (89.2%)[2]	SBM (50.0%)[2]
Arginine	3.82	3.60	4.06	3.75	3.67
Histidine	1.45	0.89	1.09	5.14	1.22
Isoleucine	2.66	1.64	2.30	0.97	2.14
Leucine	4.48	2.85	4.11	10.82	3.63
Lysine	4.72	2.93	3.06	7.45	3.08
Methionine + Cystine[3]	2.31	1.25	1.94	2.32	1.43
Phenylalanine + Tryosine[4]	4.35	2.99	3.97	8.47	4.20
Threonine	2.31	1.64	0.94	3.76	1.89
Tryptophan	0.57	0.34	0.46	1.04	0.69
Valine	2.77	2.52	2.86	7.48	2.55

[1]The percentage values for the EAA composition of each feedstuff were taken from the 1993 NRC (National Research Council, Nutrient Requirements of Fish, National Academy of Sciences, Washington, DC).
[2]Percentage of total crude protein in feedstuff.
[3]Cystine can be synthesized from methionine.
[4]Tyrosine can be synthesized from phenylalanine.

UF IFAS Extension

The Benefits of Fish Meal in Aquaculture Diets

R. D. Miles and F. A. Chapman

Table 2. Plant ingredients used in Norwegian salmon feed production in 2010 and 2013 (Nofima, 2014).

Plant ingredients (tonnes)		2012	2013
Protein sources	Soy protein concentrate	346 730	364 980
	Wheat gluten	94 137	99 348
	Sunflowermeal	97 137	65 039
	Peaprotein concentrate	12 936	7917
	Fababeans	30 753	24 971
	Dehulled horse beans	4442	
	Maize	12 509	28 640
Sum plant protein sources		598 861	590 896
Oil sources	Rapeseed oil	298 991	309 497
	Other plant oils	0	0
Sum plant oil		298 991	309 497
Binders	Wheat	161 432	158 992
	Pea	16 466	22 055
	Tapioca	3396	
Sum plant ingredients		1 079 146	1 081 439

Table C3. Range of antinutrients present in some common plant ingredients

	Ingredient					
Antinutrient	Soybean meal	rapeseed meal	Lupin meal	Pea	Faba bean	Sunflower meal
Proteinase inhibitors	X	X	X	X	X	X
saponins	X		X	X		X
phytic acid	X	X		X		
Lectins	X			X	X	
Glucosinolates		X				
phytoestrogens	X		X			
phytosteerols	X					
antivitamins	X			X		
Alkaloids			X		X	
allergens	X					
arginase inhibitor						X
cyanogens				X		
Tannins		X		X	X	
Vicine/convicine					X	

Taken from: Shepherd C J, Monroig O and Tocher D R. 2015. **Production of high quality, healthy farmed salmon from a changing raw material base, with special reference to a sustainable Scottish industry.** A study commissioned by the Scottish Aquaculture Research Forum (SARF), http://www.sarf.org.uk/cmsassets/documents/216181-554802.sarfsp007.pdf

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Some points with regard to the other ingredients

- Amino acid profiles differ – substitution of essential amino acids required during replacement
- Fatty acid profile differs – management of requirements for essential FAs required (increasing challenge with finite supplies of FO)
- Digestibility and protein levels differ (but can be remedied to an extent by additional processing – e.g. SPC)
- Micronutrient concentrations & bioavailability differ – substitution in compound feed important to meet overall requirements
- Some have potential to meet essential amino & fatty acid needs (SCP, algae) but are some way from commercial reality
- Presence of ANFs (plant materials)
- Presence of n-6 fatty acids: pro-inflammatory? Affects n-3:n-6 ratio, and is at the very least a consumer issue
- Lots of work on "substitution", in relation to growth performance, but….
- Scientific literature on FM substitution and health (disease challenge studies) unclear – both +ve and –ve effects have been noted

At least one recognised impact of changing nutritional profiles in salmon feed: LC n-3 fatty acid levels

- LC n-3 fatty acids - essential fatty acids (EFAs)
- Declining levels tracked in Scottish farmed salmon
- Nutritionally important for energy supply, cellular structure & function, and as substrates for key hormones involved in stress management & immune responses;
- Norwegian research (Nofima) on the robustness of farmed salmon fed higher n-3 concentrations indicates aquaculture system relevance;
- Link to health and welfare;
- Robustness is likely to be increasingly important in modern farming systems:
  - Sites moving offshore (higher energy)
  - Lice treatments (wellboats, cleaner fish, thermolicer)
  - Emerging disease challenges (e.g. AGD)
  - Temperature profiles

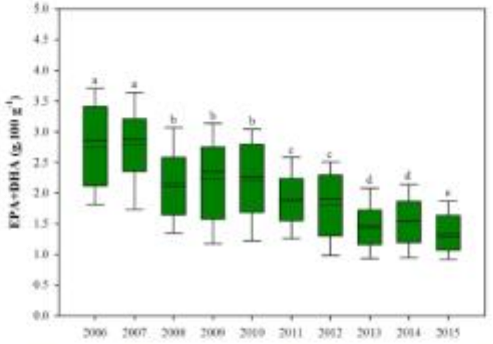

Figure 2. Levels of EPA + DHA (g.100 g^{-1}) in farmed Scottish Atlantic salmon between 2006 and 2015. Median (—), mean (···), interquartile range (box) and 10th and 90th percentiles (whiskers) are presented. Significant differences ($P < 0.05$) between mean values are indicated by different lettering (n = 106, 174, 247, 81, 85, 393, 212, 523, 546 and 687 for 2006–2015 respectively).

Sprague, M. *et al.* Impact of sustainable feeds on omega-3 long-chain fatty acid levels in farmed Atlantic salmon, 2006-2015. *Sci. Rep.* 6, 21892; doi: 10.1038/srep21892 (2016).

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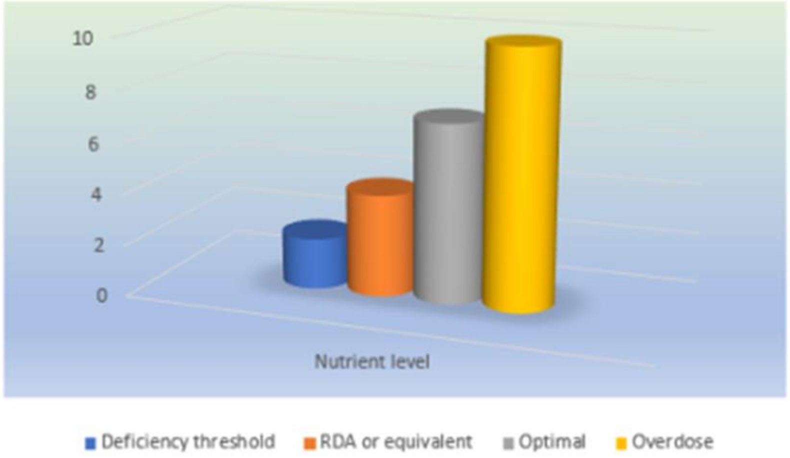
A word on fish nutritional studies and estimates of nutritional requirements for vitamins and minerals

- A science that is much more complex than terrestrial species, with >200 species;
- Different response over temperature ranges and life history stages add complexity;
- Knowledge base is largely incomplete;
- Requirements are based on minimal levels that avoid deficiency diseases (i.e. not optimal);
- Bioavailability (and toxicity) differences with organic/inorganic sources, e.g. Zn, Se;
- Potentially strong links to health with some vitamins (e.g. Vit D) and minerals (e.g. Se), but more data needed.



“Unfortunately, limited research effort has been directed to characterize the pathological changes associated with disorders linked to nutrient deficiencies in fish”

Lall, S. and Lewis-McCrea, L.M. (2007) Role of nutrients in skeletal metabolism and pathology in fish – An overview. Aquaculture 267, 3-19 doi:10.1016/j.aquaculture.2007.02.053

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Feed nutritional profile changes over time – some links with health

Source: http://uifsa.ua/en/about-fish/norwegian-salmon/salmon-farming

- Feed companies research determines growth performance (principally) in controlled environments;
- Feed companies formulate diets on "least-cost" formulations, so unlikely to be optimal for health;
- Laboratory studies may miss subtle cues, and/or impacts in farming conditions;
- Requirements may change due to other variables: temperature, life history stage, presence of stressors, farming practices, other;
- Sub-lethal effects may not be obvious (e.g. impacts on immune system functionality);
- Fatty acids so far one of best studied: "Role of EFA in immune system function is pivotal" and "affects the balance between immunosuppression and immunostimulation" (Tocher and Glencross, 2015);
- But overall situation is complex - more data needed.

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Key messages

- Nutritional replacement of fishmeal and fish oil is not straightforward even though there are 2-3 decades of practical experience;
- Substitution of FMFO with other ingredients generally requires supplementation of some micronutrients to achieve specific species' requirements;
- But…. Evidence base for nutritional needs for fish species is incomplete, and often based on the avoidance of deficiency diseases;
- Feed companies' products focused on (excel at) maintaining growth performance, rather than optimising health;
- Growth rates, FCRs have been maintained, even enhanced during a period of (partial) replacement of FMFO, but there may be health (and welfare) trade-offs;
- Those trade-offs are likely to be very subtle in connection with the farmed fish's ability to cope with stress and disease pressures;
- Optimal strategic use of FMFO is going to be important to get the most out of these high quality ingredients.

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Additional: Marine Ingredients & Aquafeed Palatability (a recognised link)

- Often overlooked
- Important: relates to feed intake, growth and FCR, and is especially important for juvenile stages in hatcheries
- Fishmeal known to play an important role (volatile compounds present?)
- High performance products e.g. fish hydrolysates increasingly available and can support

"Poor palatability is a limiting factor for replacing fishmeal with other protein sources in aquaculture"

Journal of Ocean University of China
June 2016, Volume 15, Issue 3, pp 561–567

Palatability of water-soluble extracts of protein sources and replacement of fishmeal by a selected mixture of protein sources for juvenile turbot (*Scophthalmus maximus*)

Authors | Authors and affiliations

Chun Dong, Gen He, Kangsen Mai, Huihui Zhou, Wei Xu

"The feed-palatability issue may be overcome, perhaps through the inclusion of krill meal"

Wilding, T. A., Kelly, M. S. and Black, K. D. (2006) Alternative marine sources of protein and oil for aquaculture feeds: state of the art and recommendations for further research. The Crown Estate, 63 pages, December 2006. ISBN (10): 0-9553427-4-0, ISBN (13): 978-0-9553427-4-5.

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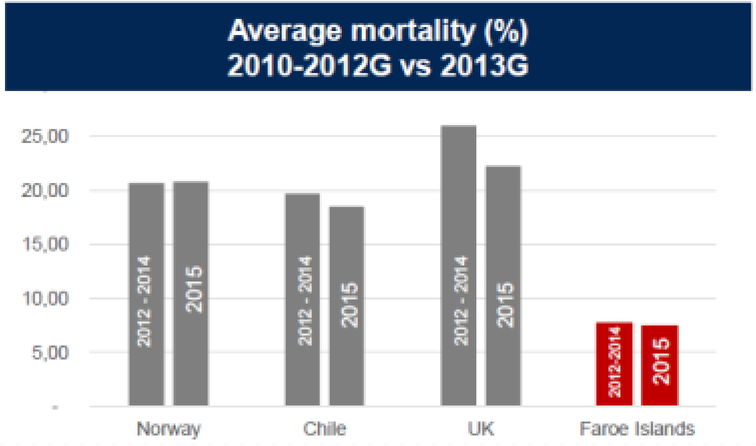
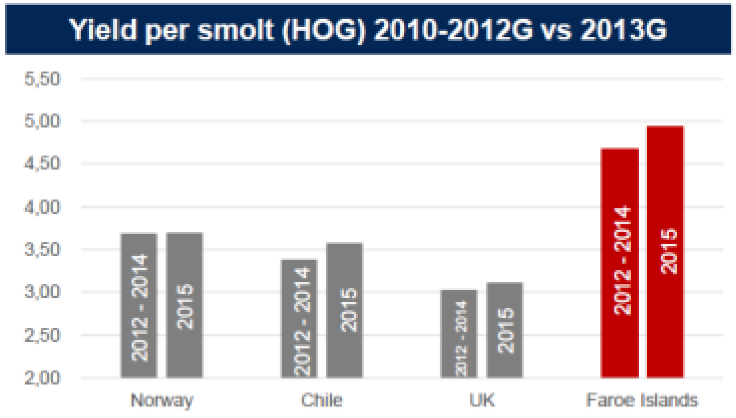
Case study – Faroe Islands

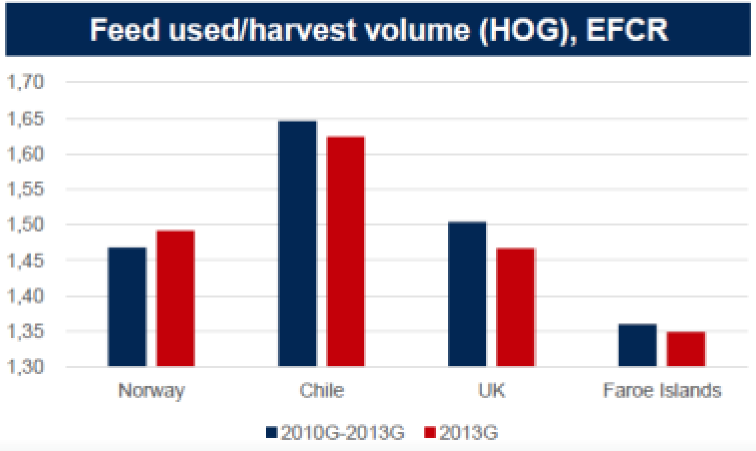
- **Comparatively high marine ingredient inclusions in salmon feed**
- **Industry reports low FCR, good survival, growth rates**
- **Anecdote – not science (and farming systems/pathogen challenge/environment differ), but suggests strong link between these factors and higher levels of FMFO**

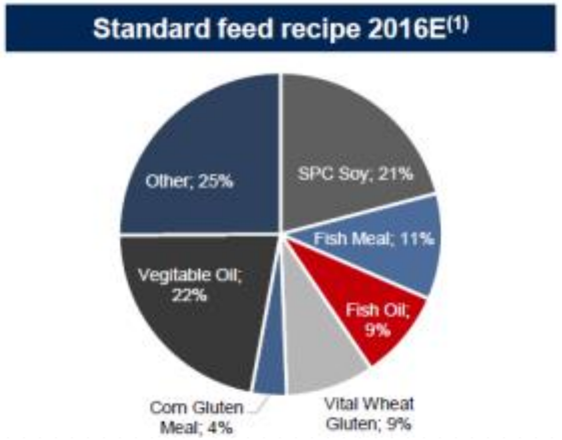
Bakkafrost data:

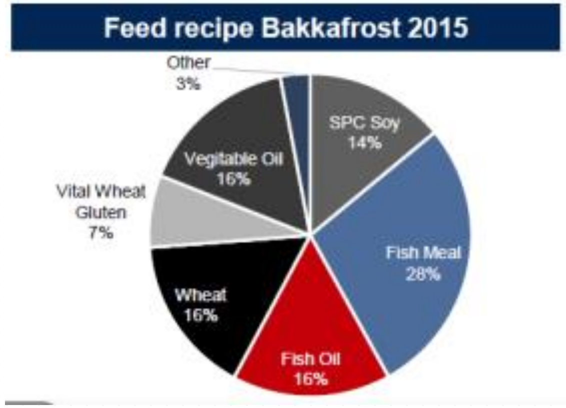
https://dsrqhvon5mja8.cloudfront.net/media/1542/bakkafrost-presentation-cmd-7-june-2016.pdf











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Summary

- Salmon feed composition has changed a great deal over time;
- Now very far from early feeds/wild diet;
- Feed companies had to innovate to continue to meet needs of sector;
- Feeds perform on growth criteria – other parameters?? (e.g. related to health);
- Macronutrient requirements easily met in feeds from a range of alternative ingredients;
- Micronutrient differences may be key, and some are known (e.g. the n-3s/EFAs) and some hypothesised (e.g. Se);
- Health impacts of substitution of FM are unclear for a range of different ingredients;
- Anecdote suggests health benefits of higher FMFO inclusions;
- Research on the health impacts of partial substitution of FMFO is going to be increasingly important for sustainable aquaculture development;
- With a finite annual supply of FMFO, optimising their incorporation in aquafeeds to maximise production efficiencies will become a priority.

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