TOWARDS NEW FEEDS FOR SUSTAINABLE AQUACULTURE

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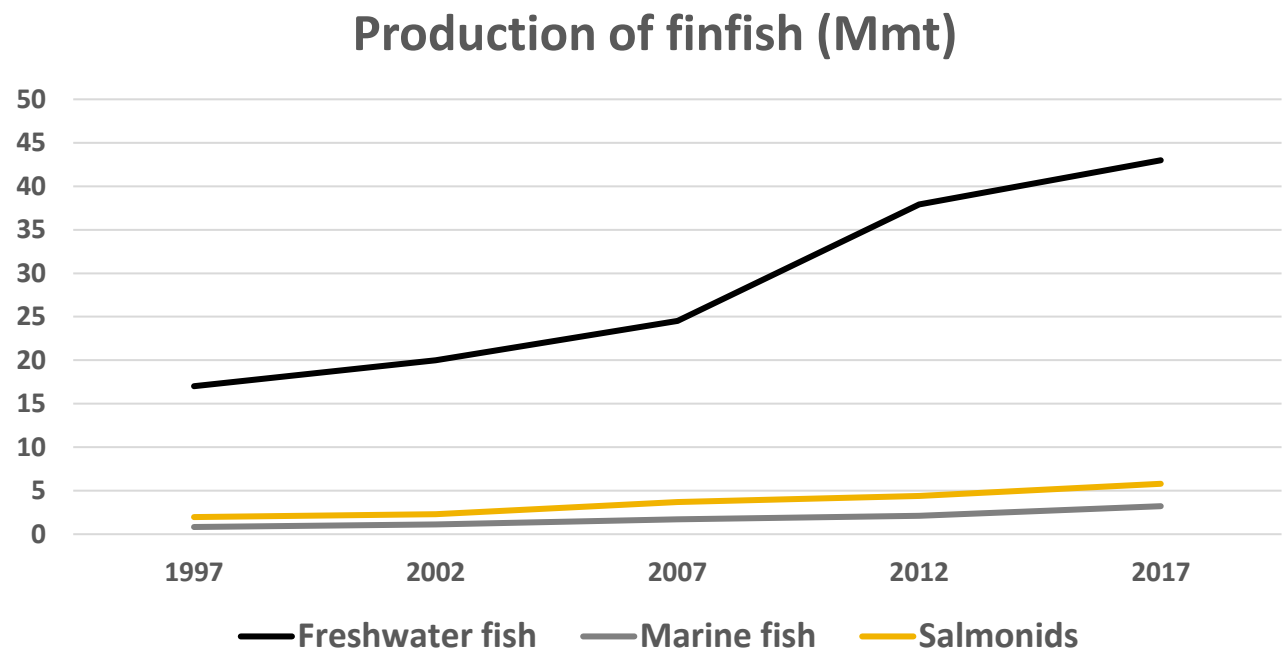
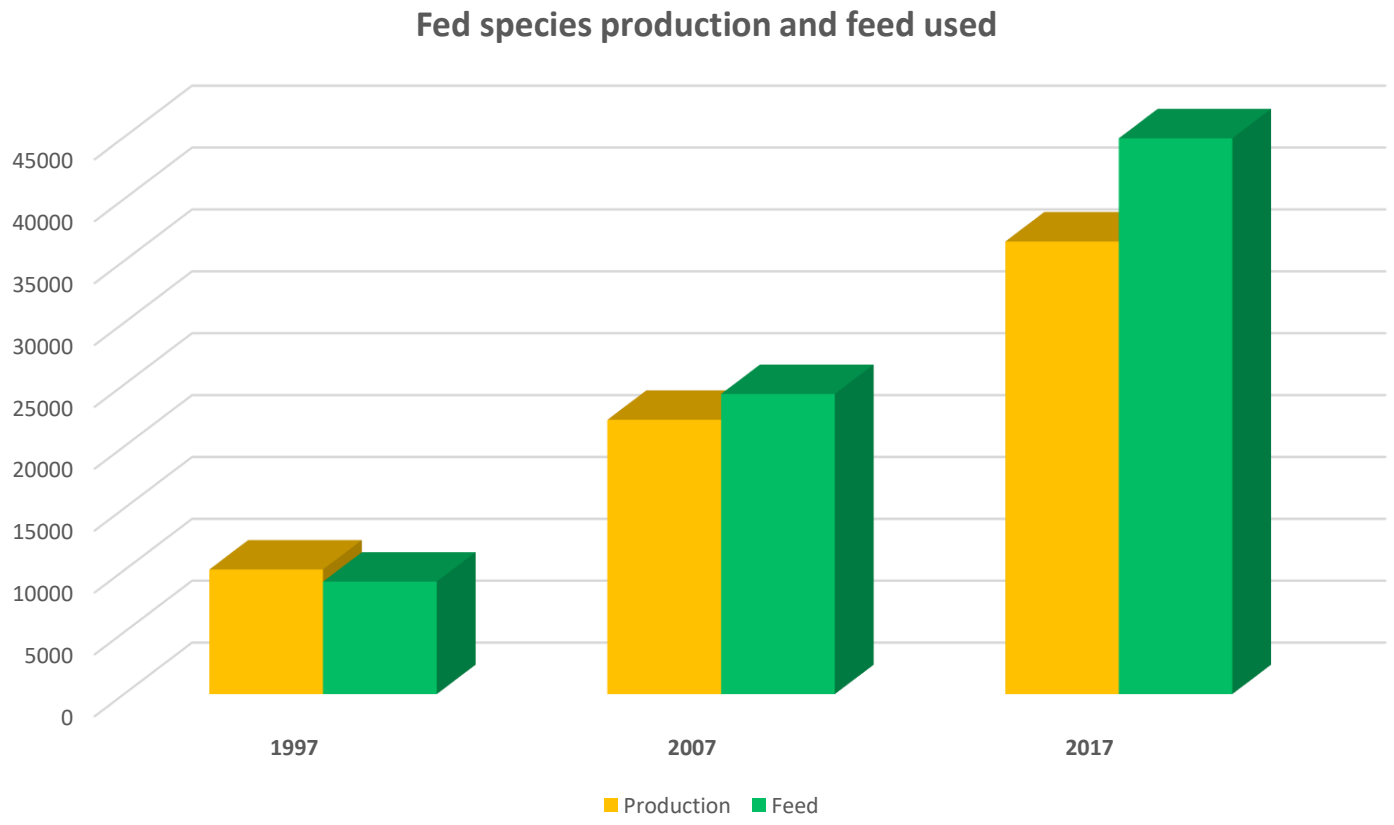
AQUACULTURE TRENDS

- Production of fed species continues to grow
- Freshwater species account for 75% of farmed fish production
  - Production increased because more fish are fed prepared feeds
  - Tilapia, catfish, carp account for most of this



AQUACULTURE TRENDS

- Intensification of freshwater production
  - Change from extensive to semi-intensive farming
  - Higher percentage of production on feed
  - Higher productivity from ponds, pens in lakes and reservoirs & in-pond raceways



PRODUCTION AND FEED USE BY SPECIES GROUP (1997 TO 2017; NAYLOR ET AL. 2021)

Species group	Total production kton, live-weight	% on feeds	Total feeds used, kton	% increase in feed used (1997-2017), %
Shrimp				
1997	933	76	1418	
2007	3544	93	5603	
2017	5512	86	7583	535
Salmon & Trout				
1997	741	100	1037	
2007	1538	100	1923	
2017	2577	100	4450	429
Marine Fish				
1997	646	53	685	
2007	1690	72	2311	
2017	3098	82	4319	631
Chinese carp (non-filter feeding)				
1997	6329	30	3797	
2007	10,736	47	8578	
2017	13,986	57	13551	357
Tilapia				
1997	931	72	1341	
2007	2575	82	3590	
2017	5881	92	9196	686
Catfish				
1997	488	83	810	
2007	2080	72	2247	
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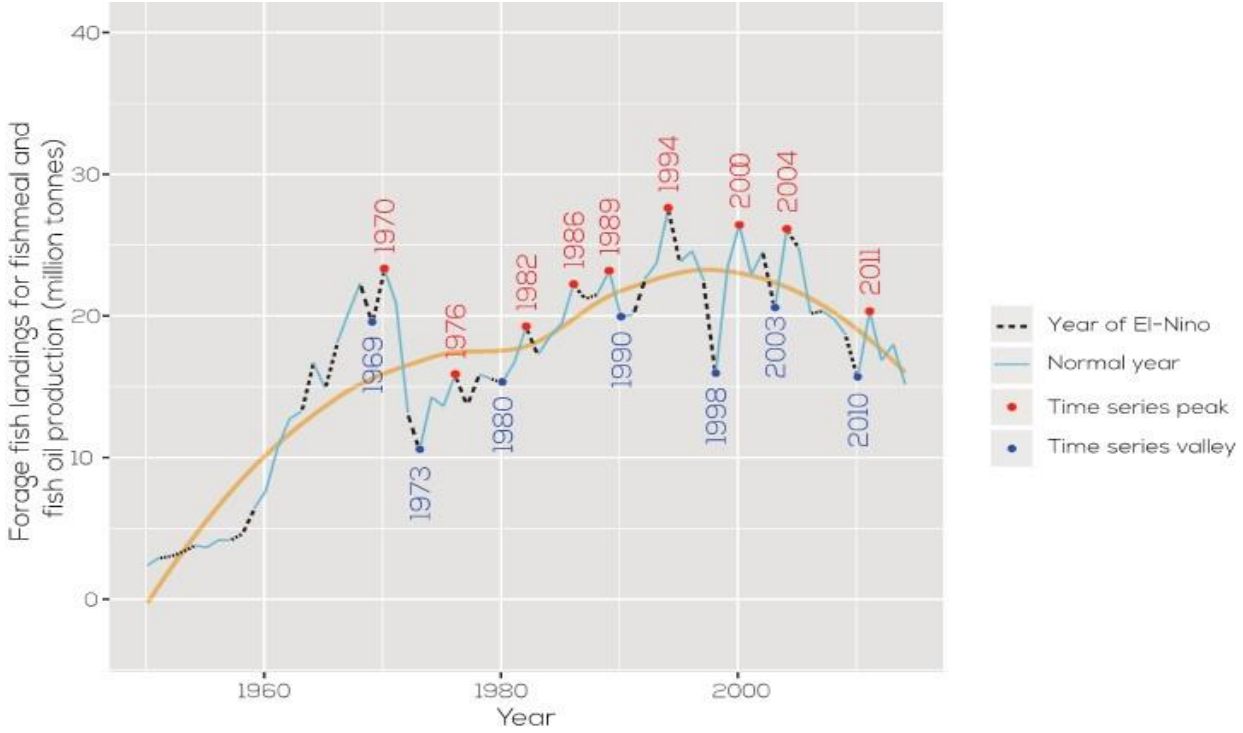
FISH FEEDS - RECENT PAST

- Fishmeal
  - FM production peaked between 1994 and 2004
  - FM has decreased since then, in part due to restrictions on landing in Peru
  - However, fish feed production has doubled since 2004, while FM use (mmt) remained the same



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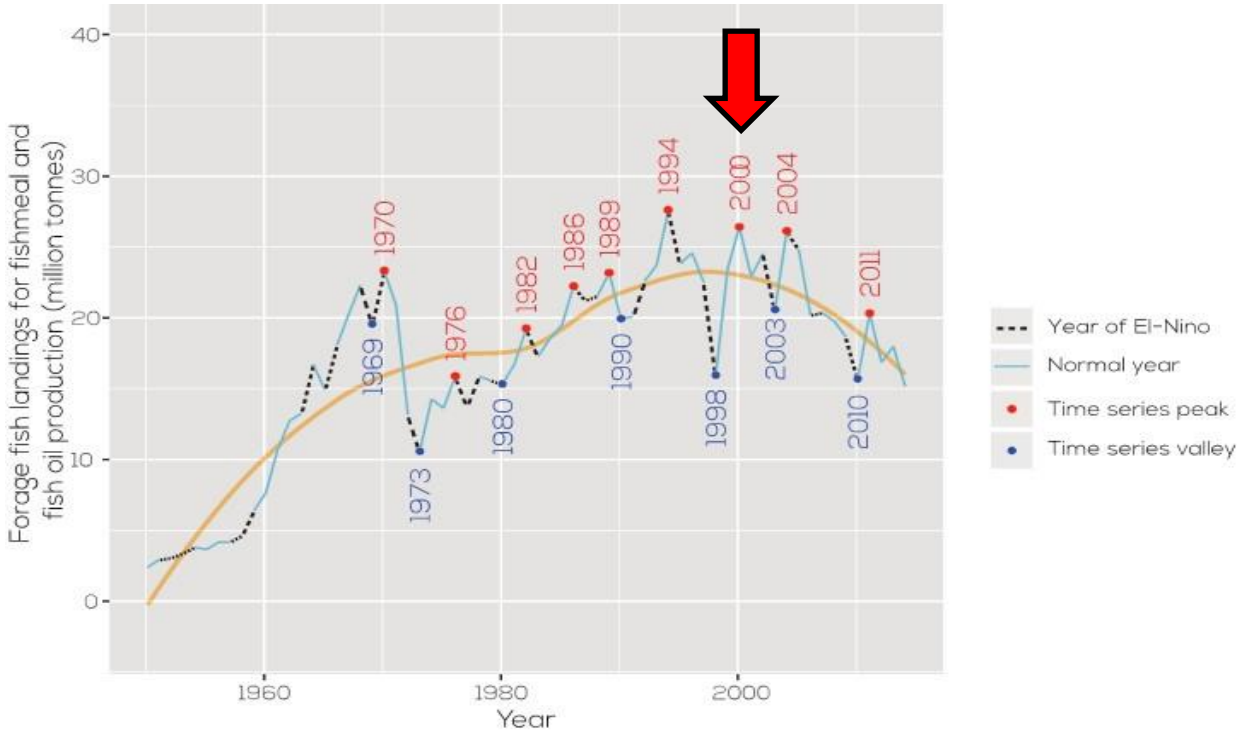


AQUACULTURE TRENDS

- **FM from seafood processing now supplies about half of the FM used in fish feeds worldwide**
- **As a result, fish in:fish out ratio has decreased for the sector except for species having high fish oil in feeds**

Table 1 | Wild fish used in aquaculture feeds for 11 commonly farmed fed fish and shellfish

Farmed fish and crustaceans[a]	Total production (kilotons)[a]	Percentage produced with compound feed (by weight)[a]	Average FCR[b]	Percentage fishmeal in feed (wild)	Percentage fishmeal in feed (trimmings)	Percentage fish oil in feeds (wild)	Net wild fish used (kilotons)	FIFO[c] in 2017
Fed carps	13,986	57	1.7	0.4	0.6	0	0	**0.02**
Tilapia	5,881	92	1.7	0.5	1.5	0	0	**0.03**
Shrimp	5,512	86	1.6	5	5	2	3,034	**0.82**
Catfishes	5,519	81	1.3	0.5	1.5	0	0	**0.02**
Marine fish	3,098	80	1.7	8	6	3	2,528	**1.25**
Salmon	2,577	100	1.3	6	6	6	4,020	**1.87**
Freshwater crustaceans	2,536	60	1.8	5	7	1	548	**0.43**
ODF fish	2,491	43	1.7	3	8	2	728	**0.38**
Milkfish	1,729	55	1.7	2		0	0	**0.07**
Trout	846	100	1.3	5	4	6	1,320	**1.82**
Eel	259	100	1.5	25	10	5	389	**2.98**
Total	44,424						12,566	**0.28**

[a]Categories from Tacon[3], Table 4. ODF, other diadromous and freshwater fish. The calculations by the authors are based on data from the following sources: production, share of production and FCR were obtained from the FAO[2] and Tacon[3]; inclusion of fishmeal and fish oil data were from the National Resource Council report on Nutrient Requirements for Fish and Shrimp[54], Naylor et al.[59], and Ytrestøyl et al.[55]; and analyses of fish trimmings in fishmeal were from Green (SeaFish)[47] and Leadbitter[44]. We use conservative estimates of 24% fishmeal and 10% fish oil recovery from wild fish.
[b]FCR is defined as the estimated average species-group economic FCR (total feed fed/total species group biomass increase). Economic FCR (also known as EFCR)[3,55,59] is defined as total feed fed/total species group biomass increase and includes waste, escapes and other non-ingested feeds[55].
[c]FIFO, wild fish inputs to fed fish output.
See Extended Data Table 3 for more information.

Naylor et al., 2021

TRENDS IN FISH FEEDS

- Sustainability
  - Alternatives to fishmeal and fish oil made from marine resources
  - Precision formulations - AA balance and protein retention
  - Fish health and wellness
    - GI tract health and immune function
- Consumer concerns
  - Quality and safety of farmed fish
    - Fillet fat level and omega-3 fatty acids
    - Contaminants (heavy metals and POPs)
    - GMO concerns
  - Value issues – sustainability, rainforest destruction, etc.
- Role of feeds in economics of aquaculture
  - Combination of survival to harvest and efficient feeds

FISH FEED SUSTAINABILITY

- Aquaculture production is expected to double by 2035
- Fish feed production will also double
- Feeds will require an additional 20mmt of protein ingredients
  - Plant protein concentrates from soy, corn, wheat, barley, sunflower, peas and other crops
  - Higher recovery and use of seafood processing wastes
  - Land animal proteins (rendered products)
  - Single-cell proteins (bacterial, yeast)
  - Insect meals

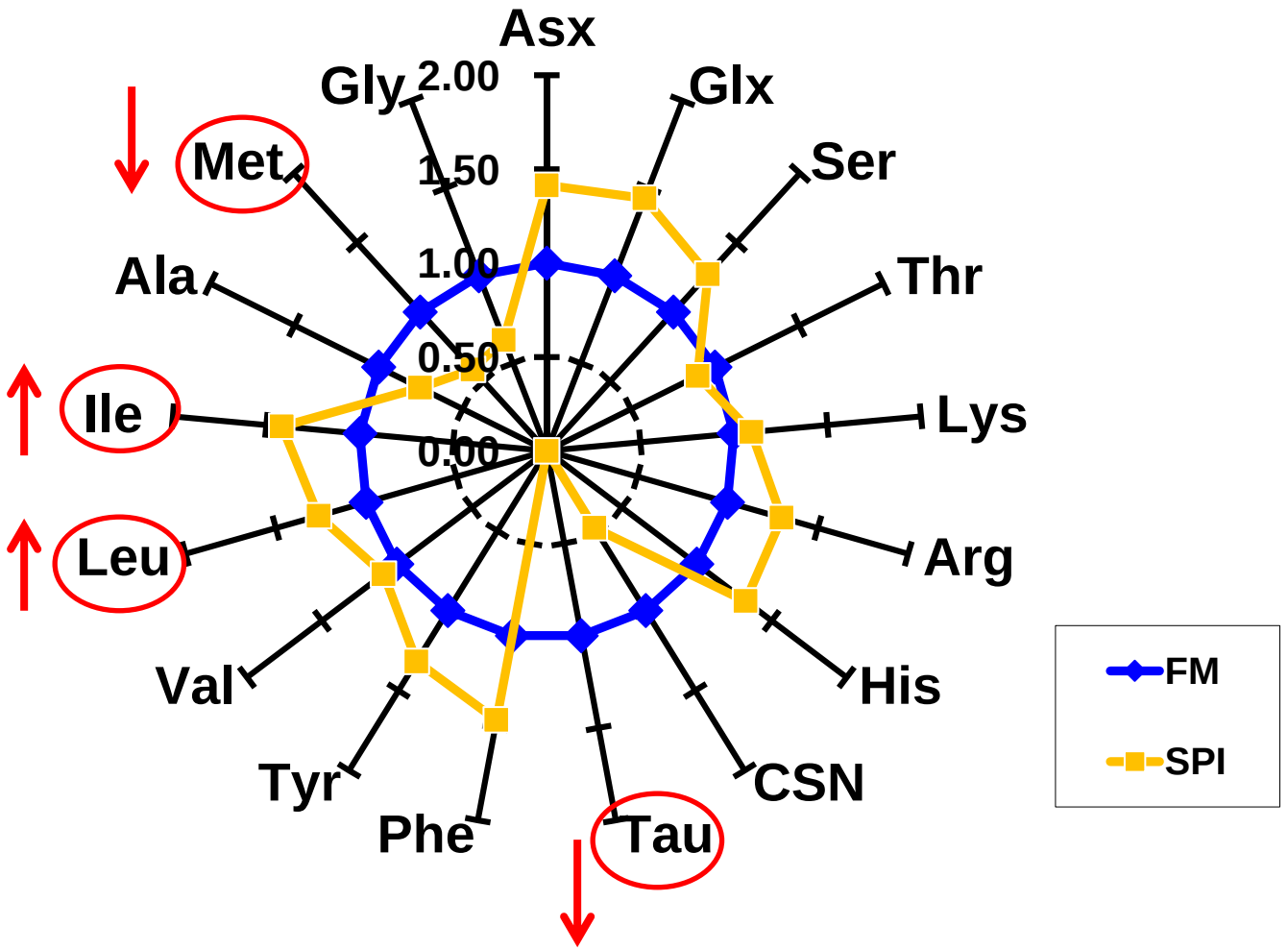
ALTERNATE PROTEIN SOURCES FOR FISH FEEDS

- Must be economically competitive with fishmeal
- Must be sustainable 'Articles of Commerce' (large quantities, transportable, familiar, etc.)
- Must fit into feed mill systems for material handling
- Must not reduce pellet quality
- Must not increase pollution from fiber or indigestible nitrogen/ phosphorus
- Must be compatible with emerging social values

NUTRITIONAL CONSIDERATIONS WITH ALTERNATE PROTEIN SOURCES

- Amino acid balance and availability
- Palatability
- Antinutritional factors
- Fiber or ash levels
- Variability in quality among sources or suppliers
- Price per unit protein

AMINO ACID PROFILE - SOY PROTEIN AND FISHMEAL



OTHER CONSIDERATIONS WITH ALTERNATE PROTEIN SOURCES

- Increasing diet efficiency – protein retention
  - Precision formulation
    - Related to amino acid profile
    - Related to amino acid digestibility and synchronization of absorption
- Fish health and wellness
  - Functional ingredients – those that affect metabolism in ways unrelated to nutrition to improve growth, efficiency or health
    - GI tract health
    - Immune function

COMMON ALTERNATE PROTEIN SOURCES FOR FISH FEEDS

- wheat gluten/corn gluten
- oilseed meals
- oilseed protein concentrates
- pea/bean protein concentrates
- rendered (animal) by-products
- fishmeal from trimmings
  - Tuna trimmings in SE Asia
  - Farmed salmon trimmings
  - This source now supplies 50% of FM in fish feeds

PROTEIN CONCENTRATES COMPARED TO FISHMEAL

	Fishmeal	Soybean meal	Sunflower protein conc.	Soy protein concentrate	Corn gluten meal	Wheat gluten meal
Protein (%)	67	48	47	62	63	80
Fat (%)	7.6	0.9	1	0.5	2.2	4.5
Lysine (%)	5.1	3.2	1.5	3.9	1.1	1.1
Methionine (%)	1.96	0.7	0.8	0.8	1.9	1.7
Price (euro/ton)*	1400	475	500	980	820	1450
Price (euro/ton protein)	2090	990	1064	1581	1367	1812

***prices delivered to Europe, April 22, 2021**

SINGLE CELL PRODUCTS

- Bacterial protein
  - Methanolic bacteria (grown on methane or methanol)
    - Easy to genetically modify to produce functional ingredients
    - High levels of nucleic acids
    - Unless shown to have functional properties, not economically competitive with alternatives at today's prices
- Distillers yeast product
  - Byproduct of ethanol production
- Microbially-enhanced soy and barley proteins
  - Solid-state fermentation using species of fungi that utilize non-soluble carbohydrates, phytate and fiber
  - Essentially operates like a rumen, upgrading poor quality feeds to high quality microbial protein

INSECT PRODUCTS

- Insect meal, mainly from black soldier fly larvae
  - Quality varies with substrate used to rear insects
    - Fatty acid profile, contamination with POPs or heavy metals
    - Insect lipids prone to oxidation unless antioxidants are added to meal
    - Insect larvae must be de-fatted to produce dry meal
- Economics and scaling up production are challenging
    - Producers need to show insect meal is a functional ingredient to justify high price

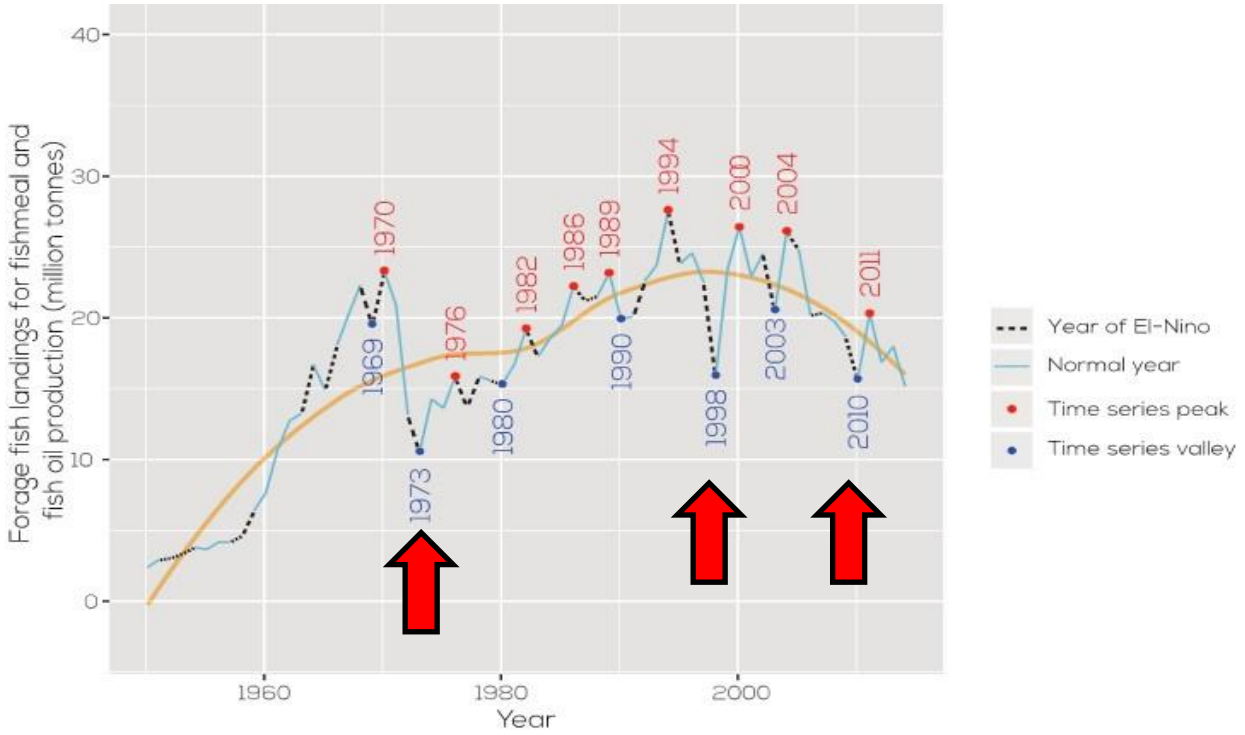
BACTERIAL AND INSECT PROTEIN MEAL COMPARISON

	Fishmeal	Bacterial protein	Black soldier fly meal (now)	Black soldier fly meal (future)
Protein (%)	67	70	55	55
Fat (%)	7.6	1.9	18	18
Lysine (%)	5.1	2.75	5	5
Methionine (%)	1.96	0.76	1.6	1.6
Price (euro/ton)*	1400	1600 (est)	3500	1500 (est)
Price (euro/ton protein)	2090	2286 (est)	6364	2727 (est)

***prices delivered to Europe, April 22, 2021**

FISH FEEDS - RECENT PAST

- Fishmeal
  - Highly variable production from year to year
  - This is mainly due to variability in Peru
    - Oceanic conditions (El Nino) affect anchovy distribution and accessibility to fisheries



CONSUMER CONCERNS AND FISH FEEDS

- Quality and safety
  - Critical need is to develop alternative sources of essential fatty acids (DHA/EPA)
    - Algae oil concentrates
    - GMO plant oils
  - Expensive today but likely economical in near future
- Social values
  - Sustainability, rainforest destruction, etc.
  - Auditing and traceability
    - Expanding beyond sourcing information
  - Young consumers more likely to pay more for responsibly-sourced farmed products

CHANGES IN FISH FEED FORMULATIONS TEND TO BE ABRUPT

- Historically they were caused by reduced anchovy landings in Peru that cut FM production in Peru
  - First was in 1973 – caused by El Nino in Peru that reduced anchovy landings
    - US catfish feeds replaced FM with soy proteins w/o any information on catfish amino acid requirements
    - Huge losses resulted, leading to large investment in fish nutrition research
  - Second was in 1998 – El Nino again, coupled with collapse of the Japanese sardine fishery
    - US catfish, salmon and trout AA requirements were known, so feeds were successfully reformulated
    - Japanese yellowtail AA requirements not known, so replacement of FM with soy protein caused huge losses – partially related to taurine
  - Third was in 2007/08 – El Nino again, but combined with massive FM purchases by China that removed >30% of FM traded between countries
    - No problem with catfish or salmonids, but problems with European seabass and sea bream due to lack of AA requirement information
    - Losses mitigated by high FM levels in feeds to start with
    - Ingredient market was stable until 2017 – African swine fever in China reduced demand for FM

NOW, OTHER EVENTS ARE DISRUPTING FISH FEED INGREDIENT MARKETS

- COVID-19 reduced demand for farmed fish
- China's problems with African swine fever
  - Over 50% of swine in China were lost between 2017 and 2019
  - This reduced demand for global fishmeal, soybean meal and corn
  - Now China's swine industry is repopulated
  - This is affecting demand and prices of fish feed ingredients
- Chinese government just decreed that swine diets will change from being soy-corn mixtures
  - This is a political decision intended to reduce dependence on imported feed ingredients

China to reduce soy and corn in feeds (Reuters, April 22, 2021)

- China issued guidelines recommending the reduction of corn and soymeal in pig and poultry feed, a measure that could reshape the flow of grains into the world's top corn and soybean buyer.
- The Ministry of Agriculture and Rural Affairs said the new guidelines are aimed at improving the usage of available raw materials and creating a formula that better suits China's conditions.
- The ministry said rice, cassava, rice bran, barley and sorghum were also suitable alternatives to corn, while rapeseed meal, cottonseed meal, peanut meal, sunflower meal, distillers dried grains, palm meal, flaxmeal, sesame meal and corn processing byproducts were good options to replace soymeal.

OTHER DISRUPTIONS OF FEED INGREDIENT MARKETS

- Land animal proteins
  - Allowed in aquafeeds but not In livestock feeds
  - Using them made it easy to formulate low FM fish feeds
  - EU will now allow poultry meal in swine feeds and swine meal in poultry feeds
  - This will increase prices for animal proteins to fish feed producers and complicate precision fish feed formulation
- Soy products (SBM and SPC)
  - Products from Brazil may be banned in the EU due to illegal and legal deforestation of the Amazon
  - SPC production in Brazil will take some time to replace
  - Regulations will increase prices for soy proteins and complicate fish feed formulations
  - Regulations in the EU affects global fish feed trends

PRIORITIES FOR FISH NUTRITION RESEARCH TO DEAL WITH IMMINENT DISRUPTION OF FEED INGREDIENT MARKETS

- Feed ingredient markets are shifting now!
  - Improved estimates of nutritional requirements of non-salmonid farmed fish species, especially marine fish
  - Apply modern genetic and physiological approaches to evaluate ingredients
  - Establish "Reference formulations" for important species are needed to benchmark new formulations
  - Identify fish strains that outperform when fed sustainable feed formulations
    - G x E
    - Marker-based selective breeding for strain improvement

FINAL PRIORITY FOR FISH NUTRITION RESEARCH

- Explore relationships between diet, fish strain and microbiome
- Define a desirable microbial communities in fish
- Develop nutritional strategies to….
  - improve intestinal health
  - reduce low-grade pathogen challenges
  - increase contribution of microbiome to nutritional needs of the fish
- High potential to improve fish feed sustainability