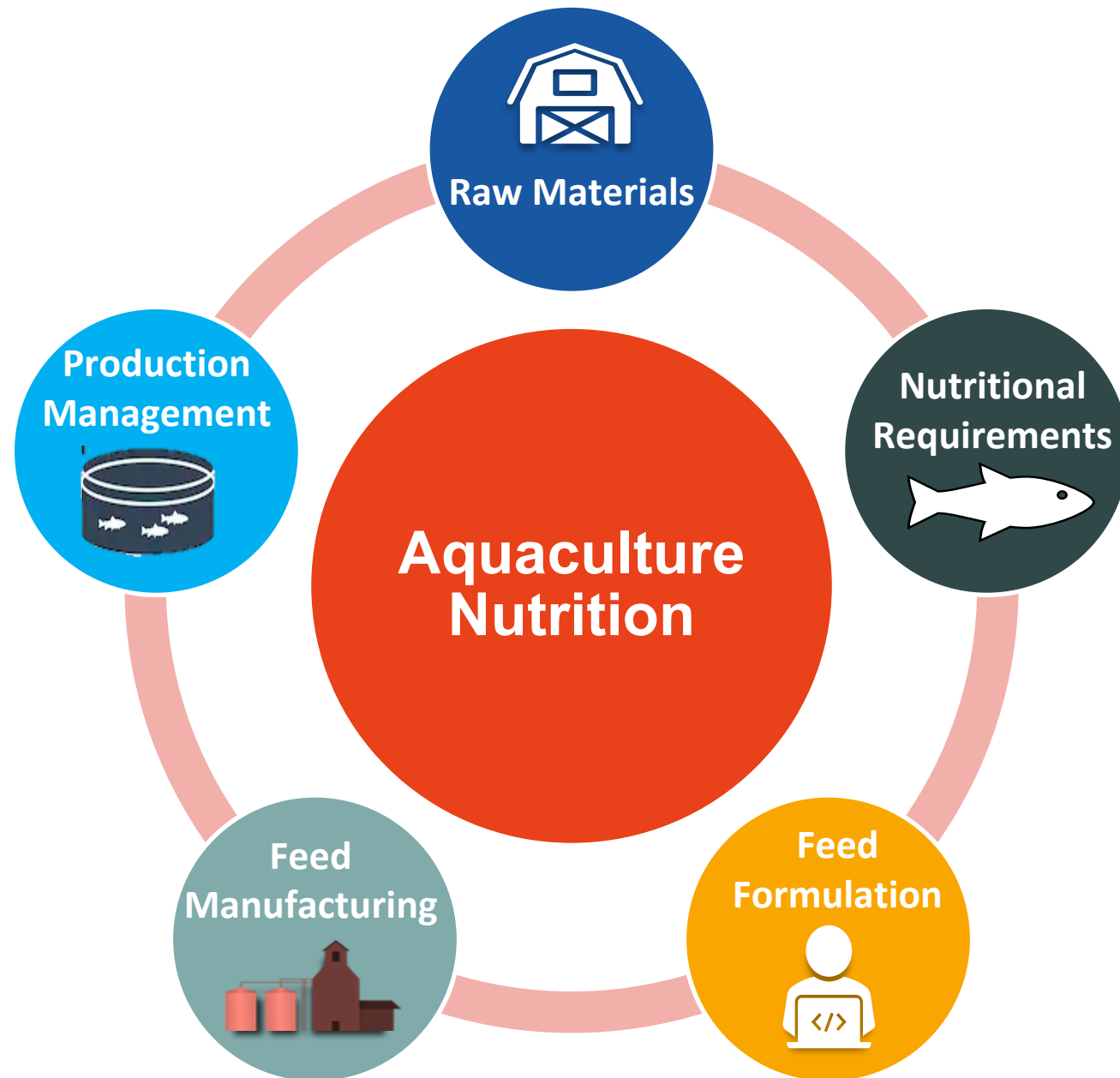


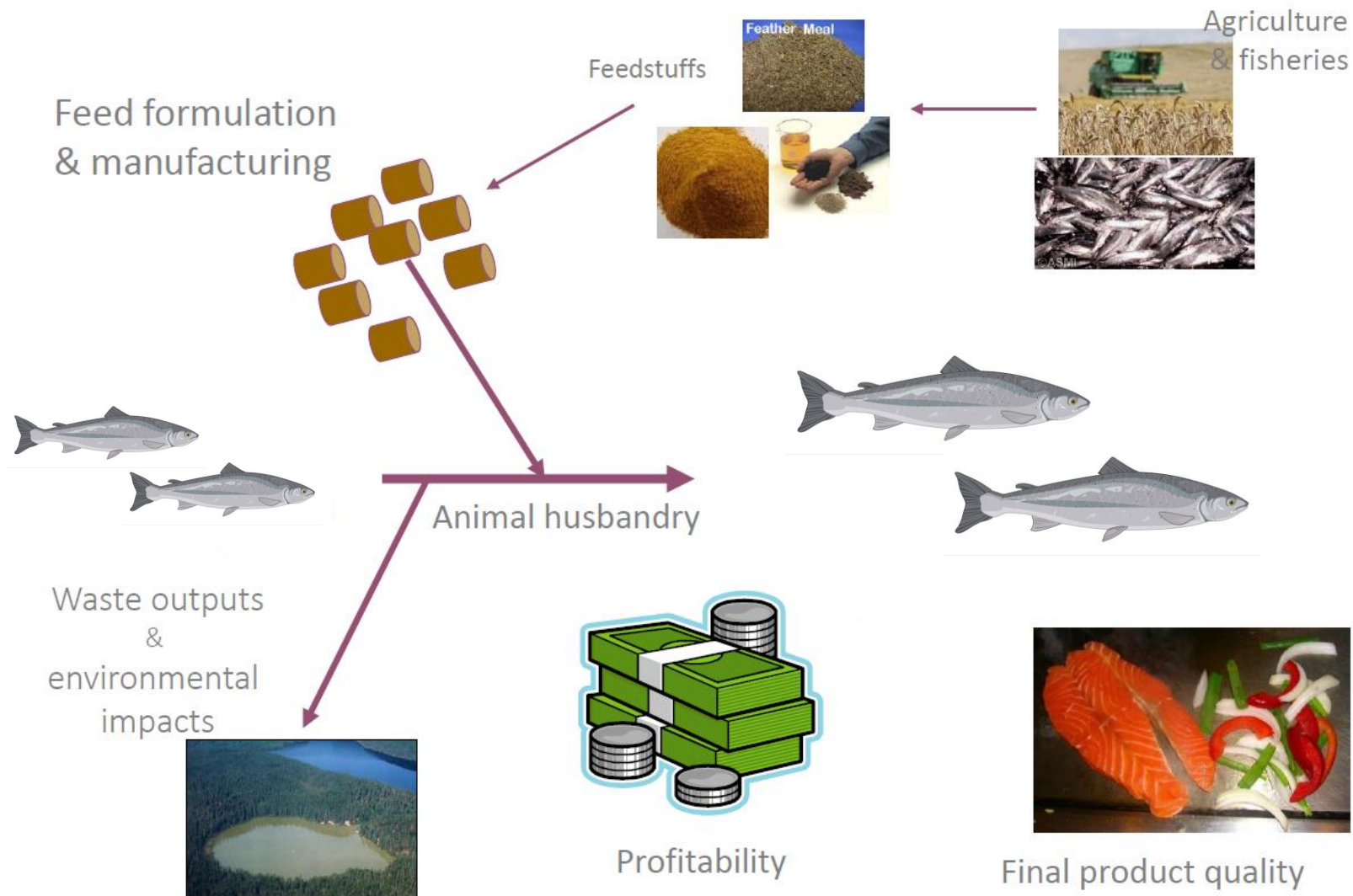
Principles of feed formulation

Dr. Jamie Hooft

Overview



Looking at the issue from a broad perspective



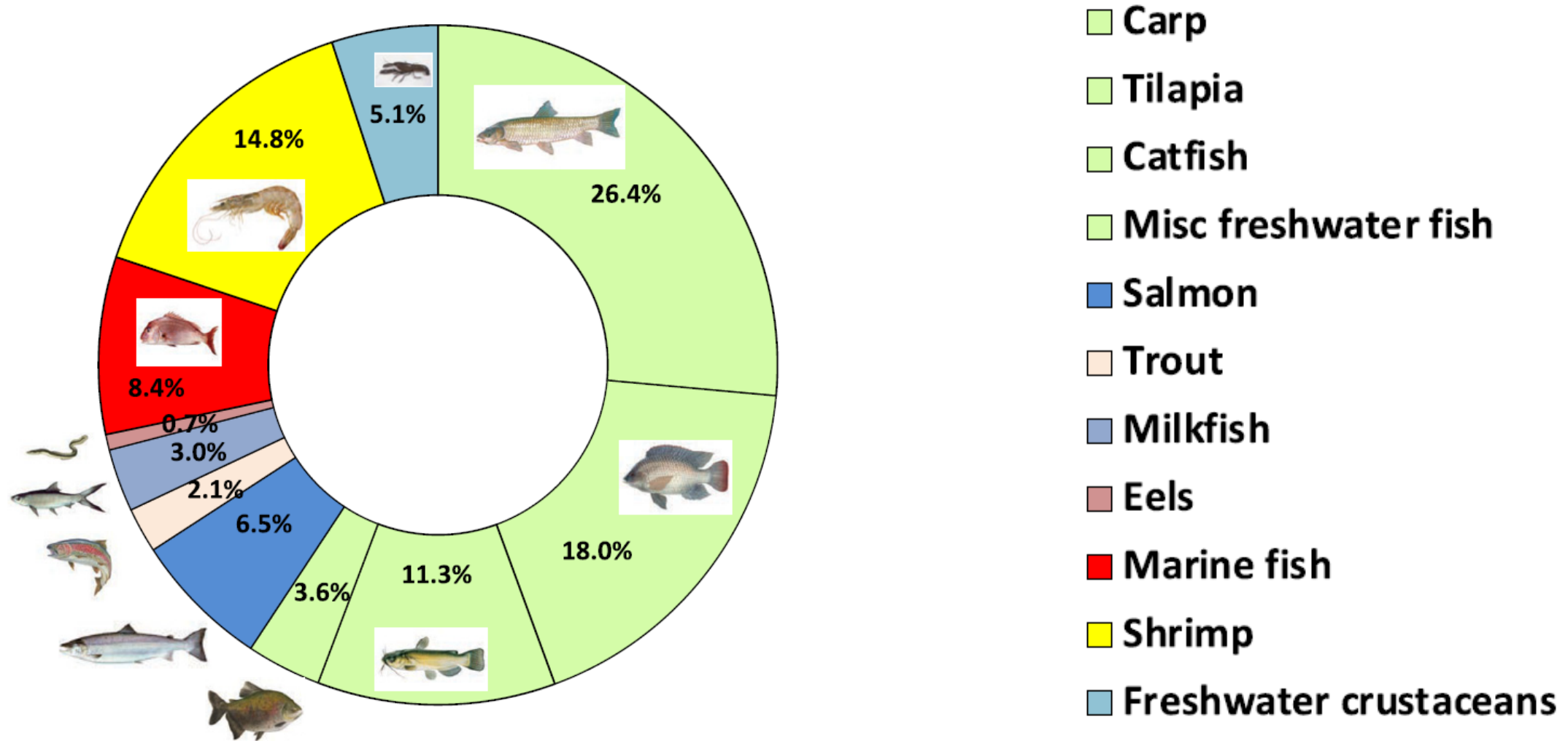
Global aquafeed production



Top major fed species groups	Tonnes live weight	APR%/yr 2000–2017	Total value US\$ billion	Estimated% on feeds	Economic FCR ^a	Feed use '000 tonnes
Chinese fed carps	13,985,593	4.0	32.3	57%	1.7	13,551
Tilapia	5,880,510	11.0	11.09	92%	1.7	9196
Shrimp	5,511,913	9.7	34.22	86%	1.6	7583
Catfishes	5,518,877	14.8	10.57	81%	1.3	5811
Marine fish	3,098,133	7.0	13.08	82%	1.7	4319
Salmon	2,577,427	5.6	18.27	100%	1.3	3350
FW crustaceans	2,526,185	11.0	24.29	57%	1.8	2,592
ODF fish	2,491,077	13.4	11.68	43%	1.7	1821
Milkfish	1,728,561	8.0	2.43	52%	1.7	1527
Trout	845,947	3.0	3.79	100%	1.3	1098
Eel	259,390	1.2	2.04	98%	1.5	381
Total	44,423,613					51,229

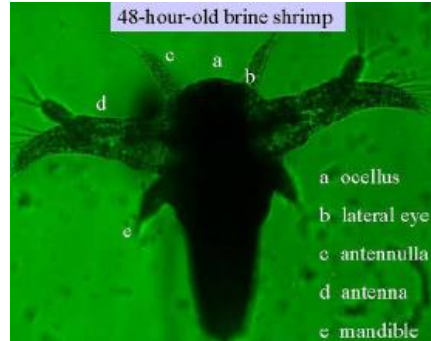
^aEconomic FCR: estimated net fish production (live weight basis) per unit of feed intake (dry weight basis).

Global compound feed usage by fed species



Types of feed

- Live feeds
- Moist and semi-moist feeds
- Dry feeds
 - Cold-pelleted
 - Steam-pelleted
 - Extruded



Shrimp

Yellowtail
Flounder
Cod
Halibut

Salmon
Sea bream
Sea bass
Trout

Tilapia
Flatfish

Eel
Milkfish

Catfish

Feed formulation



The process of quantifying the amounts of feed ingredients that need to be combined in a single uniform mixture (diet) that supplies all the nutrients required by the animal or allows for certain production objectives to be met at a reasonable cost (preferably at the least cost).

Typical formulations indicate the amount of each ingredient that should be included in the diet and then provide the concentration of nutrients (composition) in the diet.

Feed formulations are generally a compromise between an ideal situation and practical considerations (cost, availability, characteristics of ingredients, etc.).

Considerations in aquafeed formulation and production

Most aquaculture feed manufacturers have to produce feeds:

- For a wide variety of aquatic species and life stages
- With different specs for different market needs (e.g., different feed grades)
- While controlling production costs (i.e., low profit margins)
- That minimize risk for the corporation and its clients
- For clients with different challenges (e.g., diseases, limited resources)
- With costly, variable, and imperfect ingredients
- With limited resources: budget, personnel and time

and need to:

- Rely on published studies for generic information
- Rely on results from trials provided by different stakeholders for value of products

Key strategies in aquafeed formulation and production



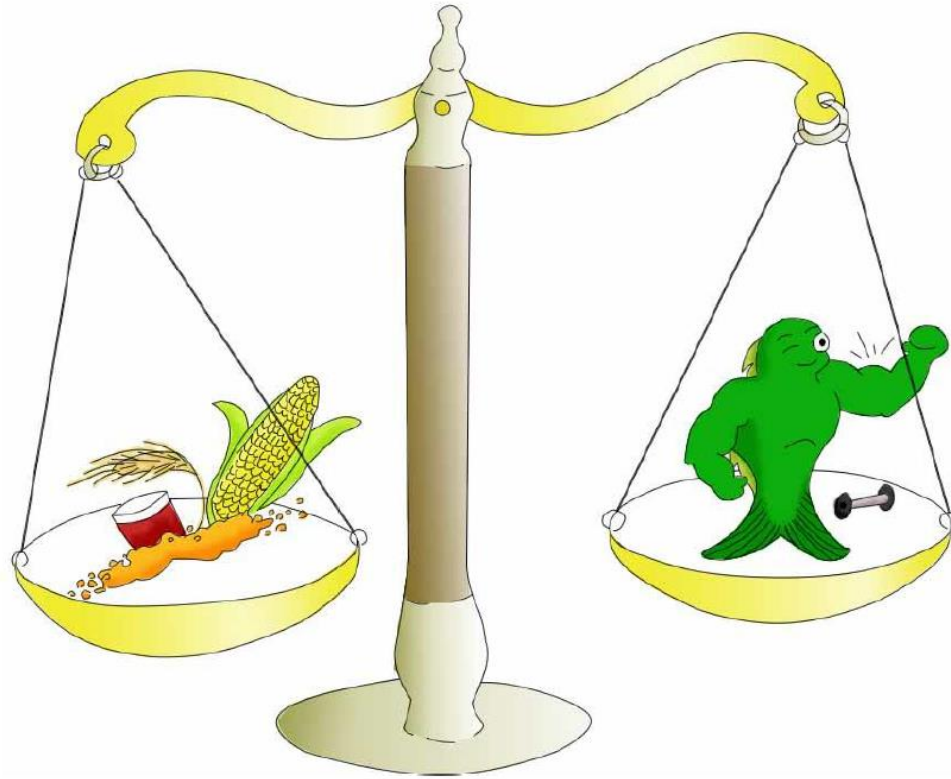
1) Determining nutrient requirements/specifications across life stages

- Fine characterization of nutrient requirements
- Research trials/review of literature
- Use of nutritional models

2) Cost-effectively meeting nutrient requirements

- Fine chemical characterization of ingredients
- Digestibility trials, *in vitro* lab analysis
- Use of nutritional models
- Use of additives and processing techniques

Balanced understanding of nutritional requirements and ingredient quality

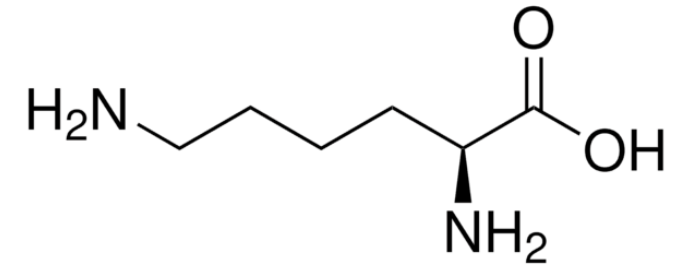


We cannot disconnect the nutritive value of ingredients and the nutritional requirements of the animal

What do fish and shrimp require?

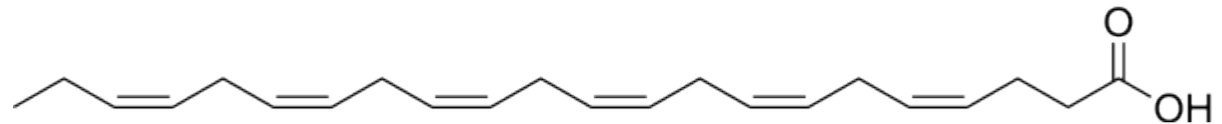


- 10 essential amino acids
- Fat and water soluble vitamins
- Minerals
- Essential fatty acids

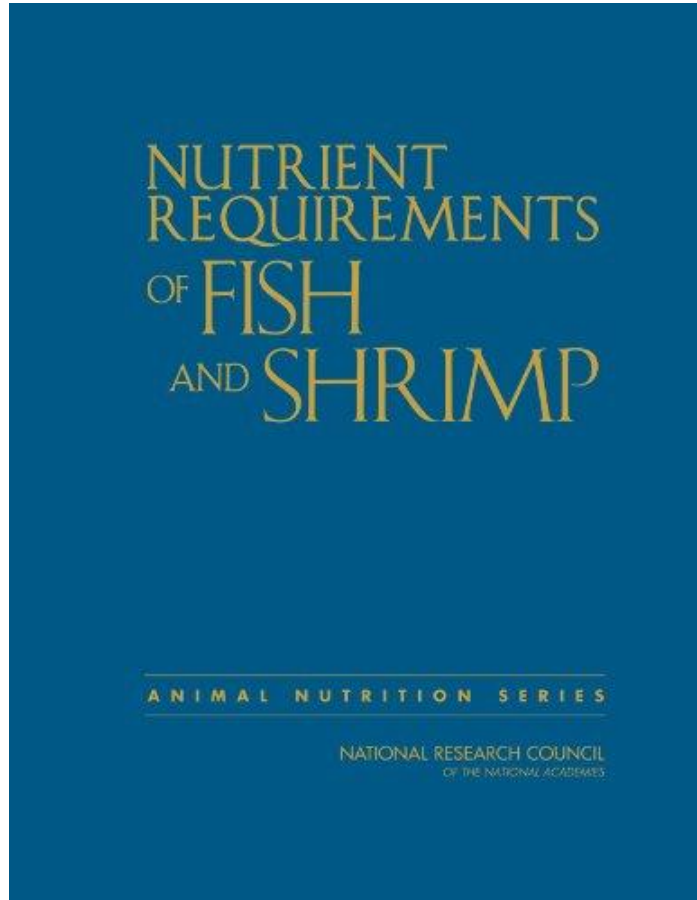


Nutrients for which essentiality is species and life stage-specific:

- Taurine
- Phospholipids
- Cholesterol?
- Nucleotides?
- Other compounds?



Available resources



IAFFD.COM



Aquaculture Species Nutritional Specifications Database (ASNS)

(v 9.0, updated 04/22/2024)

Nutrient specifications for over 30 species that are commercially important in Asia and elsewhere

[Login to access](#)



Feed Ingredients Composition Database (FICD)

(v 9.0, updated 04/22/2024)

Detailed information on the chemical composition and nutritional value of over 400 ingredients

[Login to access](#)



Practical Aquaculture Feed Formulation Database (PAFF)

(v 4.0, updated 04/22/2024)

Practical Aquaculture Feed Formulations for over 10 major species

[Login to access](#)

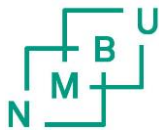
INRAE-CIRAD-AFZ Feed tables

Composition and nutritive values of feeds for cattle, sheep, goats, pigs, poultry, rabbits, horses and salmonids



IAFFD

Aquaculture Species Nutritional Specifications Database (ASNS)





Nutrition Specification Database (ASNS) v9.0 04/22/2024

Species Type
Fish

Species
Nile Tilapia

Production System
General

Stage/Live Weight Range (g)
< 5g (Starter)

Feed Target Moisture (%)
10

Export

Specification Report

Code	Specification	Short Name	Unit	Restriction Type	Value
PA02	Moisture	H2O	%	Minimum	10
PA03	Crude Protein	CP	%	Minimum	43
PA04	Crude Lipids	LIPID	%	Minimum	5
PA05	Crude Fibre	CF	%	Maximum	7
PA06	Ash	ASH	%	Maximum	
PA07	NFE	NFE	%	Maximum	
PA08	NDF	NDF	%	Maximum	
PA09	ADF	ADF	%	Maximum	
PA11	Starch	STARC	%	Minimum	19
ED01	DE Fish Carni		kcal	Minimum	
ED02	DE Fish Omni		kcal	Minimum	3358
ED03	DE Carp		kcal	Minimum	
ED04	DE Shrimp		kcal	Minimum	
ADPXF02	Dig CP -fish	DP	%	Minimum	38
ADPXF04	Dig GE (DE) - fish	DE kcal	kcal	Minimum	3581

IAFFD

Feed Ingredient Composition Database (FICD)



Feed Ingredient Composition Database (FICD) v9.0 04/25/2024

[Comparison](#)
[Filter](#)
[Export](#)

Code	Description	Dry Matter (%)	Moisture (%)	Crude Protein (%)	Crude Lipids (%)	Crude Fibre (%)	Ash (%)	NFE (%)	NDF (%)	ADF (%)
10000	Fish meal, India, 74% CP	90.8	9.2	74.16	4.97	0.5	10	1.17	0	0
10001	Fish meal, Chile, 64% CP	92	8	63.6	8.4	0.5	15.6	3.9	0	0
10002	Fish meal, Peru, 67% CP	93.9	6.1	66.95	11.5	0	15.4	0.05	0	0
10003	Fish meal, Danish, 70% CP	92.5	7.5	70.69	9.74	0.3	11.7	0.07	0	0
10004	Fish meal, Thailand, 55% CP	91.8	8.2	55	6	0.5	30	0.3	0	0
10005	Fish meal, 55% CP	90	10	54.04	8.73	0.65	23.77	2.81	0	0
10006	Fish meal, 65% CP	90.9	9.1	63.85	8.14	0.2	18.67	0.04	0	0
10007	Fish meal, 70% CP, low temperature	92	8	70	10	0	12	0	0	0
10008	Fish meal, Alaskan pollock, processing waste	94.4	5.6	69	7.6	0.5	17.3	0	0	0
10009	Fish meal, anchovy	91.9	8.1	66.95	8.83	0.7	15.4	0.02	0	0
10010	Fish meal, cod, processing waste	92	8	70.2	5.6	0	16.2	0	0	0
10011	Fish meal, freshwater alewife	93	7	65.7	12.7	0	14.6	0	0	0
10012	Fish meal, herring, 70% CP	92.5	7.5	70.69	9.74	0.3	11.7	0.07	0	0
10013	Fish meal, mackerel	93.5	6.5	67.25	10.65	0.25	15.05	0.3	0	0
10014	Fish meal, menhaden, Special Select	92.7	7.3	63.26	8.61	0.3	20.44	0.09	0	0
10015	Fish meal, processing by-products, NOAA, Seat...	88.7	11.3	69.52	7.58	0	11.6	0	0	0
10016	Fish meal, red fish	92.1	7.9	61.33	8.85	0.56	21.05	0.31	0	0



Practical Aquaculture Feed Formulation Database (PAFF) v4.0 04/22/2024

Specification

Atlantic Salmon - Grower

eFCR: 1.09

Life Stage: 250-600g

Export

Feed Formulations

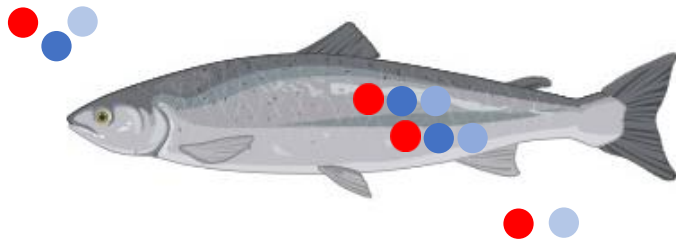
IAFFD Code	Ingredient	Inclusion (%) ↓
10002	Fish meal, Peru, 67% CP	16
31610	Wheat, flour	15.66
23005	Poultry by-product meal, low ash, 62% CP	12
52105	Canola oil	10
50105	Fish oil, anchovy	8.26
30347	Corn gluten meal, 68% CP	8
31218	Soy protein concentrate, 65% CP	5.7
20003	Blood meal, whole, spray-dried	5
14004	Krill meal	3
21001	Feather meal A, 77% CP	3
31252	Soybean meal, USA, 48% CP	3
31607	Wheat gluten meal, 78% CP	3
51106	Poultry fat	3
54105	Soy lecithin	2

Calculated Composition (As is basis)

Nutrient	Unit	Value
Dry Matter	%	93.15
Crude Protein	%	42.00
Crude Lipid	%	28.00
Crude Fibre	%	1.11
Ash	%	6.67
NFE	%	15.37
Starch	%	10.24
Dig CP -fish	%	37.50
DE Fish Carni MJ	MJ/kg	20.76
DE Fish Carni kcal	kcal/kg	4962
Arginine	%	2.49
Histidine	%	1.24
Isoleucine	%	1.76
Leucine	%	3.88

What's important in feed formulation?

- Individual nutrient requirements of animals (with adequate safety margins)
- Nutrient content of feed ingredients and associated variability
- Digestibility and bio-availability of nutrients
- Potential limitations (e.g. contaminants, anti-nutritional factors)
- Impacts (e.g. physical properties, waste outputs, final product quality) of the ingredients



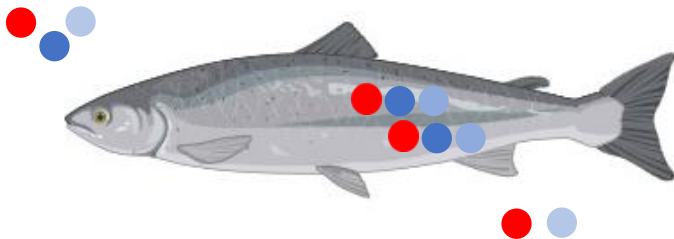
What's important in feed formulation?

- Primary objectives are to produce a mixture that (is):
 - Nutritionally balanced
 - Economical
 - Palatable
 - Water stable
 - Minimizes waste output and effect on water quality
 - Produces a desirable final product
- Practical considerations:
 - Ingredient price and availability
 - Anti-nutritive factors
 - Pelletability of mixture
 - Storage and handling requirements



Requirement vs. recommendation/specification

- Requirement
 - Minimum amount necessary for maximum growth
 - Young, fast growing fish are used in general
 - Parameters other than growth may be used
- Recommendation
 - Requirement + safety margin for losses + margin for other sources of variations



Proper estimation of the nutritional value of ingredients



- Dry matter
- Crude protein
- Crude lipid
- Ash
- Gross energy
- Macro and micro mineral composition
- Amino acid composition
- Fatty acid composition



Variability in nutrient composition



Composition	Fish meal		Poultry by-Products Meal		
	Herring	Menhaden	Feed-grade	Prime	Refined
Dry matter, %	93	91	97	96	97
Crude Protein, %	71	61	62	66	70
Crude fat, %	9	9	11	8	10
Ash, %	12	22	15	15	11
Phosphorus, %	2.4	3.1	2.6	2.8	2.0
Lysine, %	5.4	4.2	3.7	3.7	4.6
Methionine, %	1.8	1.5	1.2	1.3	1.5
Histidine, %	2.2	1.2	1.4	1.2	1.5
Threonine, %	3.1	2.4	2.5	2.4	3.0

Variability in nutrient composition



Chemical composition of DDGS samples collected from different plants

	Mean	SEM (n=12)	Minimum	Maximum
Nutrient Content (% as is)				
Dry Matter	87.68	0.20	85.72	89.85
Crude Protein	26.59	0.29	23.47	31.19
NDF	31.60	0.50	25.48	37.40
Fat	9.99	0.20	7.75	12.40
Starch	2.91	0.45	1.33	13.54
Phosphorus	0.78	0.01	0.59	0.88
Sulphur	0.57	0.02	0.39	1.03

Formulation in feed companies

Nutritionist

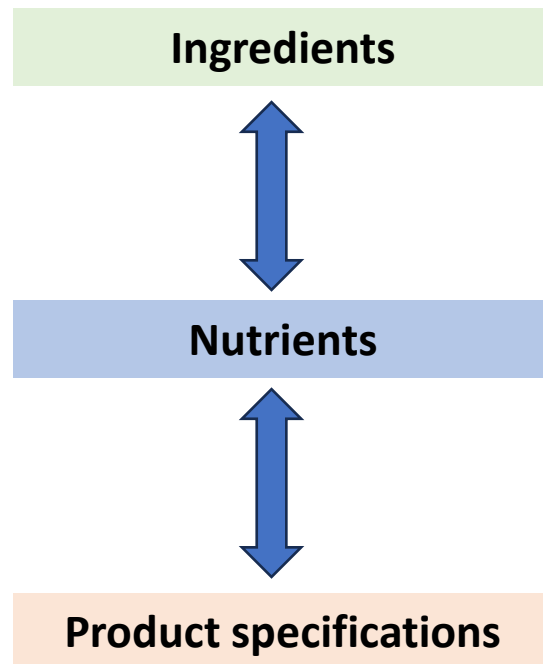
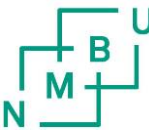
- Designs products based on species, lifestage, farming system and method, climatic factors, and market expectations
- Determines nutritional and physical specifications
- Approves raw materials, fixes upper and lower inclusion levels based on nutritional and feed processing factors
- Provides feeding recommendations
- Drives R&D and conducts trials, reports field performance of the feed, etc.



Formulator

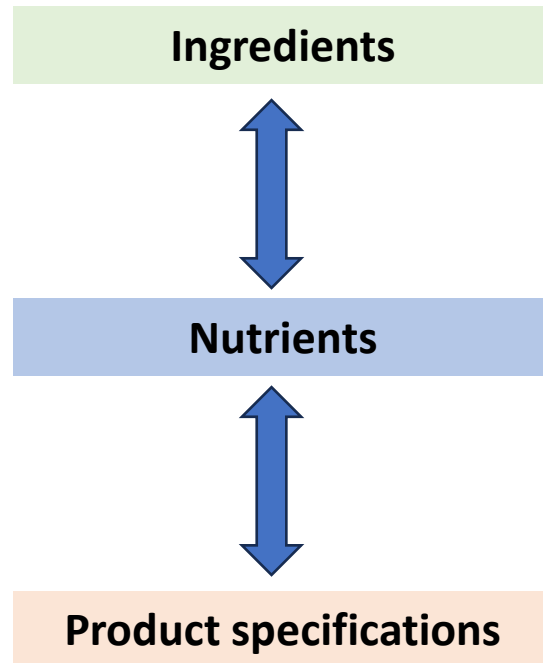
- Executes matrices and models to account for variations in the quality of raw materials
- Factors in the cost and availability of raw materials (present and future)
- Gross margin management
- Organizes audits of the formulation, especially constraints analysis
- Provides advice on raw material requirements and prices

LP-based feed formulation



Nutrient	Unit
Moisture	%
Crude protein	%
Crude fat	%
Crude fiber	%
Ash	%
Macro minerals (calcium, phosphorus, sodium, etc. Phosphorus is usually expressed on an available basis)	%
Trace minerals (zinc, manganese, iron, copper, selenium, etc.)	mg/kg
Amino acids (arginine, histidine, lysine, methionine, etc. The amino acids are usually expressed on a digestible basis)	%
Fatty acids and other lipid components (linoleic acid, linolenic acid, EPA, DHA, cholesterol, phospholipids, etc.)	%
Starch and nonstarch polysaccharides	%
Energy (usually expressed as digestible energy for aquafeeds)	kcal/kg or MJ/kg
Vitamins (vitamin A, thiamin, riboflavin, etc.)	IU/kg, mg/kg, or µg/kg

LP-based feed formulation

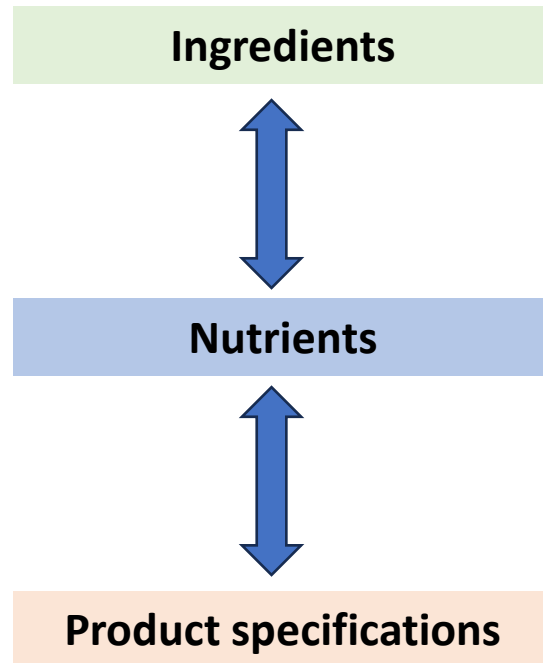


Nutrient	Unit	Value
Dry matter	%	88.00
Crude protein	%	46.30
Crude fat	%	2.70
Crude fiber	%	4.50
Ash	%	7.20
Digestible energy	kcal/kg	3150.00
Calcium	%	0.35
Phosphorus	%	0.64
Available phosphorus	%	0.25
Sodium	%	0.03
Linoleic	%	1.25
Potassium	%	0.05
Linolenic	%	0.16
Arginine	%	2.70
Lysine	%	2.72
Methionine	%	0.61
Met + Cys	%	1.24
Threonine	%	1.82
Digestible arginine	%	2.34
Digestible lysine	%	2.30
Digestible methionine	%	0.52
Digestible Met + Cys	%	1.05
Digestible threonine	%	1.59
Choline	mg/kg	2706.00

Ingredient restrictions

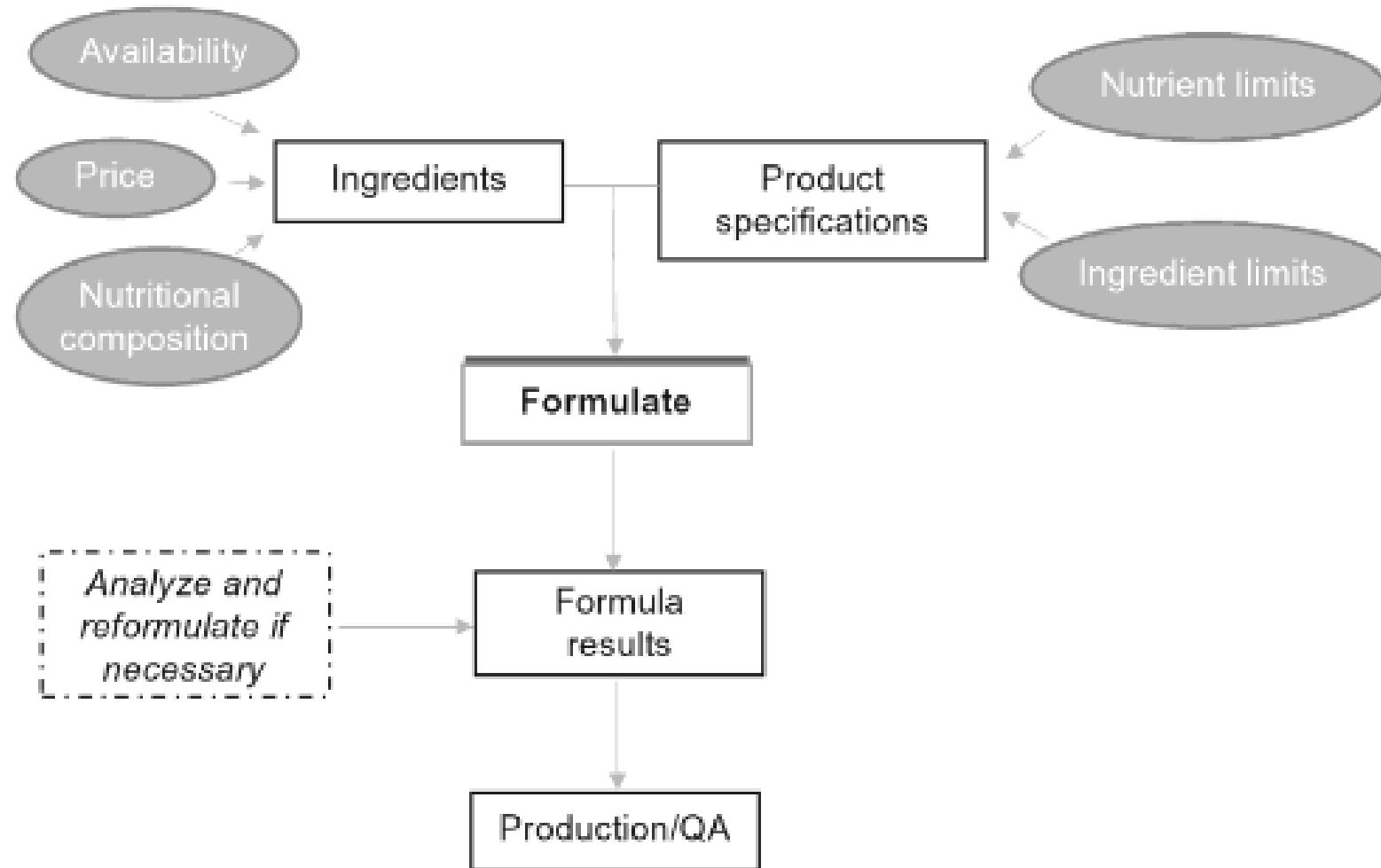
- Generally driven by practical considerations and gaps in knowledge
- Considerations:
 - Effect on processing (handling limitations, effect on pellet quality, etc.)
 - Logistical, risk management and market issues (limited availability, contamination, variability, customer concerns, export regulations, etc.)
- In general, the more we characterize the animals and the ingredients, the less important the ingredient specifications
- However, some logistical considerations still always play a role

LP-based feed formulation

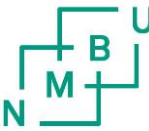


	Minimum	Maximum
(A) Nutrient specifications		
Crude protein, %	28	
Crude fat, %	5.5	
Crude fiber, %		4
Ash, %		15
Digestible energy, kcal/kg	2600	
Digestible lysine, %	1.43	
Digestible methionine + cysteine, %	0.9	
Digestible threonine, %	0.74	
Linoleic acid, %	0.8	
Linolenic acid, %		
Available phosphorus, %	0.5	
Calcium, %		2.5
Sodium, %	0.4	
Potassium, %	1.0	
Magnesium, %	0.15	
Vitamin C, mg/kg	50	
Choline, mg/kg	500	
(B) Ingredient specifications, %		
Fishmeal, 62% protein		50
Soybean meal, 46% protein		10
Rapeseed meal		25
Poultry by-product meal, 55% protein		5
Blood meal, spray-dried		30
Maize	20	15
Rice bran		
Dicalcium phosphate		
Salt		1
Limestone		1
Fish oil	0.5	
Vegetable oil		
Vitamin premix	0.1	
Lysine HCl		
DL-methionine		
L-threonine		
Trace mineral premix	0.5	
Mold inhibitor	0.2	

Overview of the formulation process



Examples of LP-based feed formulation software

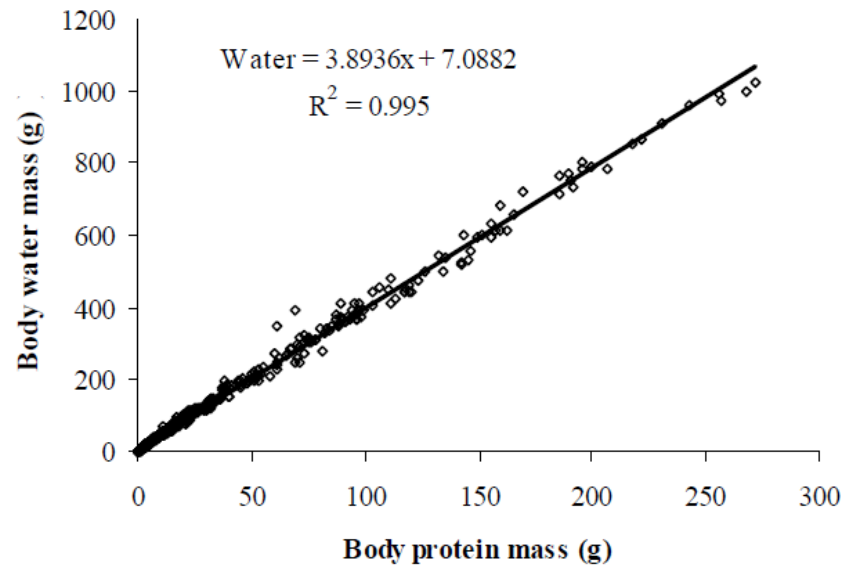


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1																				
2	Select Country	Indonesia			Remove Spill															
3	Select Species	Walking catfish spp.						eFCR	1.3		0.879799919									
4																				
5	Ingredient Name	price	min	max	Ingredient Inclusion	Check		nutritional parameters	min	max	Nutrient Composition	Check		Group	min	max	Group Inclusion	Check		Cost
6	Wheat gluten meal, 73% CP USSEC	\$ 2 483.00	0	100	-	TRUE		dry_matter	0	100	90.21	TRUE		fish_meal	5	100	5.00	FALSE		\$ 560.75
7	Blood meal, spray-dried, USSEC	\$ 1 126.00	0	100	-	TRUE		crude_protein	30	100	30.01	TRUE		fishery_byproducts	0	5	-	TRUE		
8	Hydrolized fish protein concentrate USSEC	\$ 790.00	0	100	-	TRUE		crude_lipids	0	6	6.00	TRUE		crustacean_by_products	0	100	-	TRUE		
9	Wheat flour USSEC	\$ 472.00	0	10	8.56	TRUE		crude_fibre	0.00	100	4.75	TRUE		other_marine_products	0	100	-	TRUE		Matrix Setup
10	Cassava meal USSEC	\$ 315.00	0	12	12.00	TRUE		ash	0.00	100	7.36	TRUE		blood_meal	0	3	3.00	TRUE		
11	Fish meal, SE Asia, 57% CP	\$ 1 014.00	0	100	5.00	TRUE		nfe	0.00	100	42.10	TRUE		feather_meal	0	100	-	TRUE		
12	Fish meal, SE Asia, 65% CP	\$ 1 608.00	0	100	-	TRUE		starch	17.42	100	20.61	TRUE		meat_and_bone_meal	0	10	1.31	TRUE		
13	Squid liver meal	\$ 944.00	0	100	-	TRUE		dig_protein	26.40	100	26.40	TRUE		porcine_meal_and_byproducts	0	0	-	TRUE		SOLVE
14	Meat and bone meal, 50% CP	\$ 769.00	0	100	1.31	TRUE		de_fish_carni_mj	0.00	100000	12.97	TRUE		poultry_meal_and_byproducts	0	10	-	TRUE		
15	Corn gluten meal, 62% CP	\$ 909.00	0	100	-	TRUE		de_fish_carni_kcal	3100.00	100000	3 100.00	TRUE		corn_gluten_meal_and_products	0	15	-	TRUE		
16	Corn, grain	\$ 413.00	0	100	-	TRUE		arginine	1.44	100	2.03	TRUE		corn	0	8	-	TRUE		
17	Distillers dried grains with solubles, DDGS	\$ 420.00	0	100	-	TRUE		histidine	0.64	100	0.92	TRUE		cottonseed_meal_and_products	0	100	-	TRUE		
18	Rice bran	\$ 336.00	0	100	15.00	TRUE		isoleucine	0.96	100	1.17	TRUE		ddgs	0	10	-	TRUE		
19	Soybean meal, Argentina, dehulled, Standard, 46% CP	\$ 545.00	0	100	-	TRUE		leucine	1.94	100	2.35	TRUE		rapeseed_meal_and_products	0	100	-	TRUE		
20	Soybean meal, USA, dehulled, Standard, 46% CP	\$ 559.00	0	100	39.21	TRUE		lysine	1.74	100	1.78	TRUE		rice_and_byproducts	0	15	15.00	TRUE		Clear
21	Wheat pollard	\$ 252.00	0	100	11.75	TRUE		methionine	0.54	100	0.54	FALSE		soybean_meal	0	45	39.21	TRUE		
22	Fish oil, tuna, white oil	\$ 1 608.00	0	0	-	TRUE		phenylalanine	0.98	100	1.51	TRUE		sunflower_meal	0	100	-	TRUE		
23	Squid oil	\$ 1 692.00	0	100	-	TRUE		threonine	1.10	100	1.11	TRUE		wheat_and_byproducts	0	100	20.32	TRUE		
24	Fish oil, SE Asia	\$ 1 280.00	0	100	2.56	TRUE		tryptophan	0.24	100	0.39	TRUE		marine_oil	0	100	2.56	TRUE		Reset Min/Max
25	Palm oil	\$ 1 259.00	0	100	-	TRUE		valine	1.24	100	1.63	TRUE		land_animal_oil	0	100	-	TRUE		
26	Soy lecithin	\$ 1 329.00	0	2	-	TRUE		cystine	0.27	100	0.45	TRUE		plant_oil	0	100	-	TRUE		
27	Vitamin premix, USSEC standard, fish grower, 0.5%	\$ 7 692.00	0.5	0.5	0.50	TRUE		tyrosine	0.88	100	0.97	TRUE		wild_fm	0	100	5.00	TRUE		
28	Mineral premix, USSEC Standard, fish, 0.25%	\$ 962.00	0.25	0.25	0.25	TRUE		taurine	0.00	100	0.02	TRUE		wild_fo	0	100	2.56	TRUE		
29	Rovimix-stay-C 35, ascorbyl-monophosphate, DSM	\$ 4 196.00	0.05	0.05	0.05	TRUE		linolenic_18_3_n_3	0.00	100	0.14	TRUE								
30	Choline chloride, 60% choline	\$ 1 154.00	0.6	0.6	0.60	TRUE		epa_20_5_n_3	0.00	100	0.23	TRUE								
31	L-Lysine	\$ 2 098.00	0	0.5	-	TRUE		dha_22_6_n_3	0.00	100	0.15	TRUE		Sustainability Indicator						
32	DL-Methionine	\$ 3 846.00	0	0.5	0.10	TRUE		epa_dha	0.30	100	0.38	TRUE		FIFO	0	100	0.36	TRUE		
33	L-Taurine	\$ 4 545.00	0	0.5	-	TRUE		Sum_n_3	0.55	100	0.57	TRUE		FFDRm	0	100	0.27	TRUE		
34	Mono calcium phosphate, MCP, Ca(H2PO4)2.H2O	\$ 1 224.00	0	0.5	-	TRUE		linoleic_18_2_n_6	0.00	100	1.20	TRUE		FFDRo	0	100	0.66	TRUE		
35	Salt, NaCl	\$ 91.00	0	0.5	-	TRUE		arachidonic_20_4_n_6	0.00	100	0.05	TRUE								
36	Limestone (Calcium Carbonate)	\$ 42.00	0	0.5	-	TRUE		Sum_n_6	0.43	100	1.39	TRUE								
37	Mold inhibitor (calcium propionate)	\$ 2 671.00	0.05	0.05	0.05	TRUE		phospholipids	0.00	100	0.65	TRUE								
38	Mycofix Secure, BIOMIN	\$ 1 399.00	0.03	0.03	0.03	TRUE		cholesterol_mg_kg	0.00	10000	460.36	TRUE								
39	BHT, powder, 0.1%	\$ 2 622.00	0.025	0.025	0.03	TRUE		calcium	0.00	100	0.89	TRUE								
40								phosphorus	0.76	100	0.94	TRUE								
41								dig_p_carni	0.40	100	0.40	FALSE								
42								Total	100.00	100	100.00	TRUE								
43																				



Nutrient requirements: Protein and amino acids

- Protein is not a “nutrient” per se
 - Amino acids are the nutrients
- Protein deposition drives live weight (biomass) gain
 - Due to close association of water with protein



Protein deposition = biomass gain
 1 g of protein deposited + 4 g water gain $\approx$ 5 g biomass gain

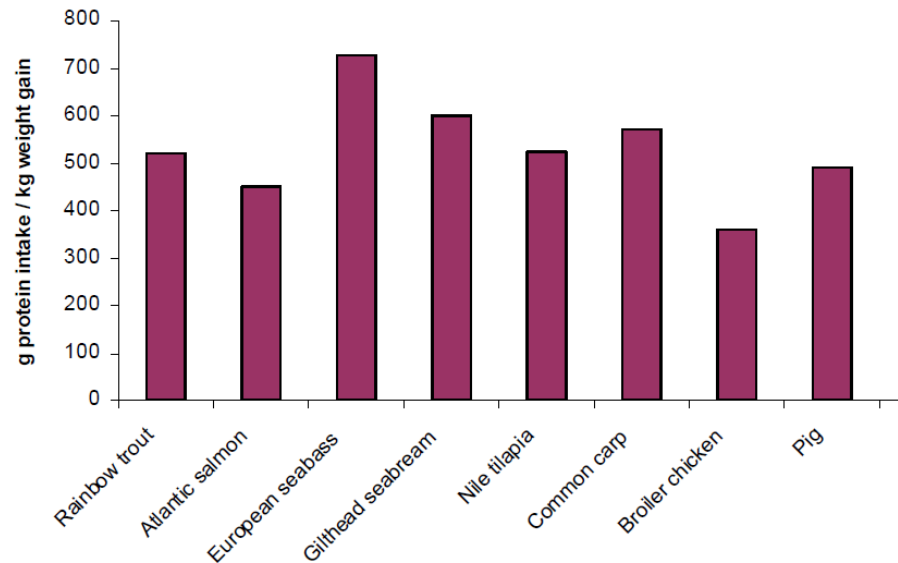
Dietary protein levels

Recommended protein levels (%) for fish species of commercial importance (as-fed basis)

Species	Weight Range				
	<20 g	20-200 g	200-600 g	600-1,500 g	> 1,500 g
Atlantic salmon	48	44	40	38	34
Rainbow trout	48	40	38	38	36
Pacific salmon	55	45	40	38	38
Channel catfish	44	36	32	32	28
Common carp	45	38	32	28	28
Nile tilapia	40	34	30	28	26
European sea bass	55	50	45	45	-
Gilthead sea bream	50	45	40	40	-

Do fish have a high protein requirement?

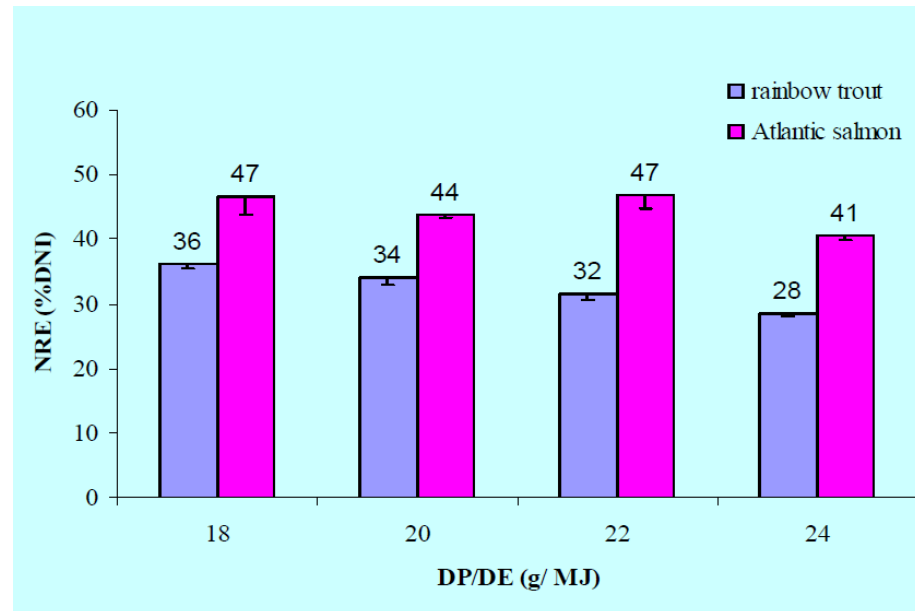
- Protein requirement in terms of dietary concentration (% diet) is high
- Absolute requirement (g protein/kg body weight gain) is not
- Fish have a lower absolute energy requirement than mammals which results in similar g body weigh gain/g protein ingested as in mammals, but better feed efficiency (gain: feed)



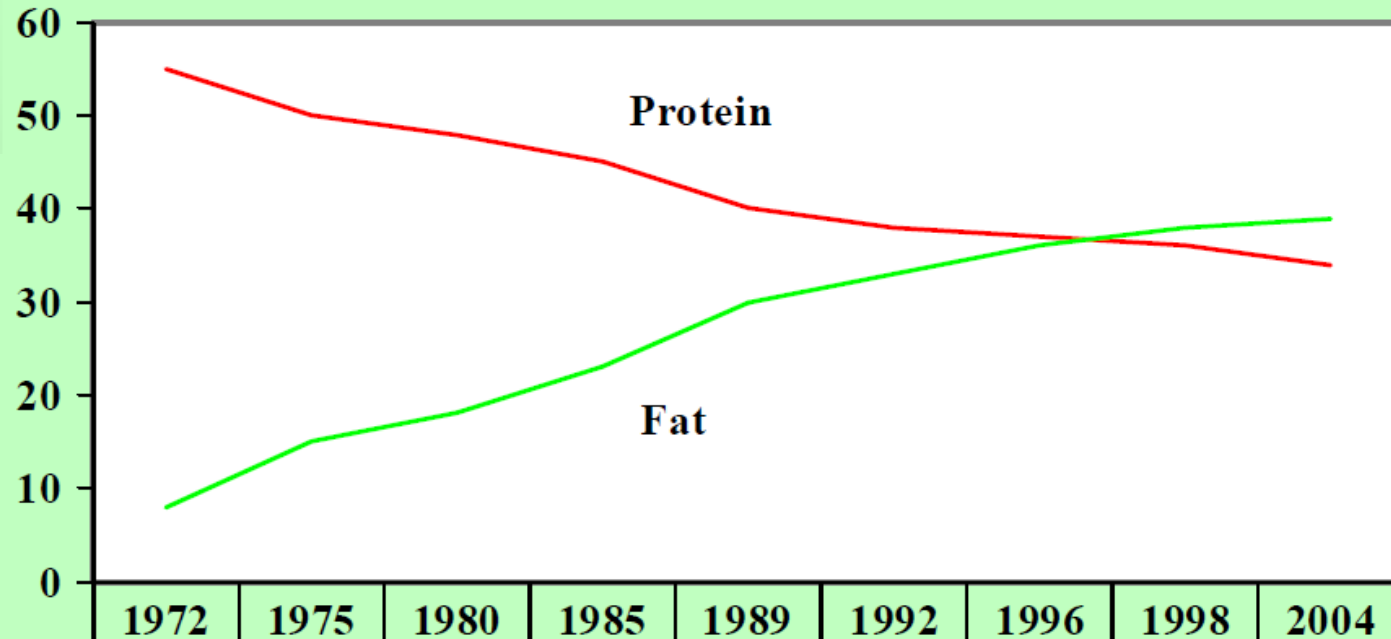
Protein intake per kg of live weight gain in different fish species, chicken and swine

Digestible protein to digestible energy ratio

- Protein (amino acids) are used as a major energy source
- Other energy-yielding nutrients (e.g. lipids) in adequate amounts can reduce dietary protein (amino acid) catabolism and requirement
- Referred to as protein-sparing effect of lipids
- Protein requirement should be expressed as digestible protein to digestible energy ratio (DP:DE)



Protein and lipid development in salmon feed



— Protein %	55	50	48	45	40	38	37	36	34
— Fat %	8	15	18	23	30	33	36	38	39

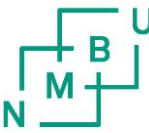
Grower feed Norway

Greatly reduced amount of feed needed for one kg biomass gain

Evolution of Canadian rainbow trout feed

Ingredients (% diet)	1973	1989	1991	1995	1998	2002
Fish meal, herring, 68% crude protein (CP)	35	20	35	18	18	22
Blood meal, spray-dried, 80% CP	-	9	9	-	-	6
Corn gluten meal, 60 % CP	-	17	15	49	37.6	28
Soybean meal, 48% CP	20	12	14	-	-	-
Poultry meal, 68% CP	-	-	-	-	13	12
Brewer's dried yeast, 45% CP	-	-	-	6	-	-
Wheat middlings, 17% CP	33	20				12
Whey, 12% CP	-	8	10	11	9	-
Vitamin premix	1.5	0.5	0.5	1	0.5	0.5
Mineral premix	1.5	0.5	0.5	1	0.5	0.5
L-Lysine	-	-	-	-	1.4	1
Fish oil	6	13	16	14	20	13
Plant oil	-	-	-	-	-	5
Digestible Composition						
Digestible protein (DP, %)	35	44	44	44	42	43
Digestible energy (DE, MJ/kg)	14	20	20	20	21	20
DP/DE (g/MJ)	25	22	22	22	20	22
Expected FCR	1.6	1.3	1.15	1.15	1.15	1.15

Amino acids



Essential	Abbreviations	
Arginine	Arg	R
Histidine	His	H
Isoleucine	Ile	I
Leucine	Leu	L
Lysine	Lys	K
Methionine	Met	M
Phenylalanine	Phe	F
Threonine	Thr	T
Tryptophan	Trp	W
Valine	Val	V
Non-Essential		
Alanine	Ala	A
Asparagine	Asn	N
Aspartate	Asp	D
Cysteine *	Cys	C
Glycine	Gly	G
Glutamate	Glu	E
Glutamine	Gln	Q
Proline	Pro	P
Serine	Ser	S
Tyrosine *	Tyr	Y

10 amino acids are indispensable (essential) to fish

*conditionally essential

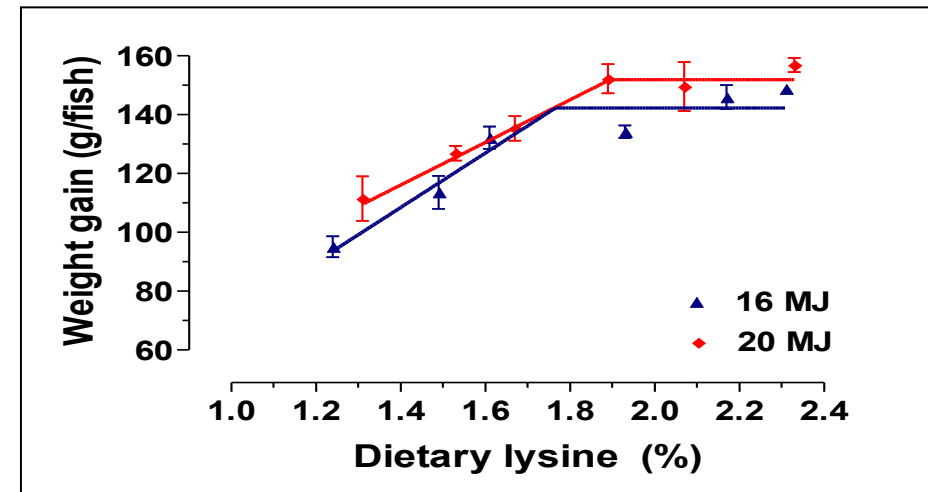
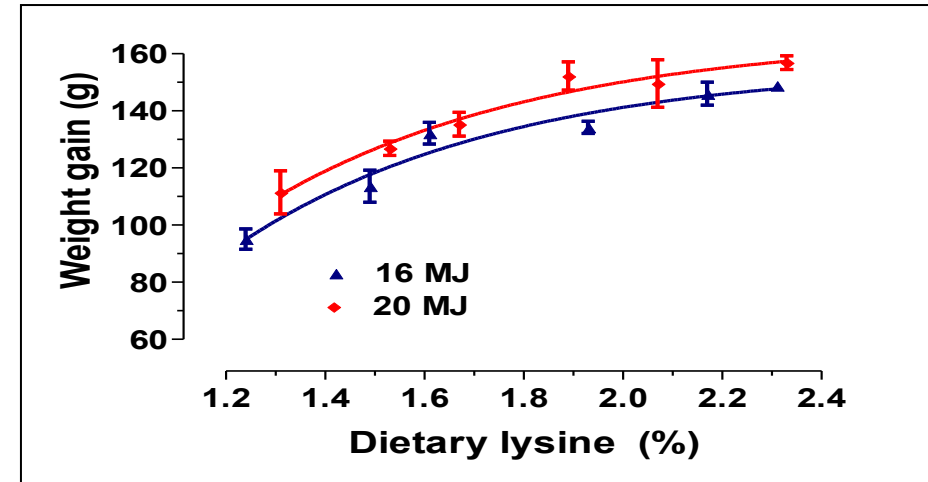
EAA requirements across life stages

Amino Acid (% diet DM)	Weight class						
	0.2-20 g		20-500 g		500-1,500		>1,500 g
	RT	AS	RT	AS	RT	AS	AS
Arg	1.91	1.79	1.77	1.82	1.62	1.70	1.46
His	0.83	0.80	0.77	0.80	0.69	0.75	0.64
Ile	1.27	1.32	1.19	1.32	0.98	1.22	1.04
Leu	2.26	2.31	2.11	2.31	1.78	2.14	1.82
Lys	2.47	2.55	2.31	2.54	1.92	2.35	2.00
Met+Cys	1.32	1.28	1.23	1.30	1.10	1.21	1.03
Phe+Tyr	2.49	2.71	2.33	2.68	1.82	2.46	2.09
Thr	1.77	1.55	1.63	1.60	1.60	1.51	1.30
Trp	0.43	0.35	0.40	0.37	0.42	0.35	0.30
Val	1.90	1.75	1.76	1.79	1.64	1.67	1.44

Estimation of nutritional requirements

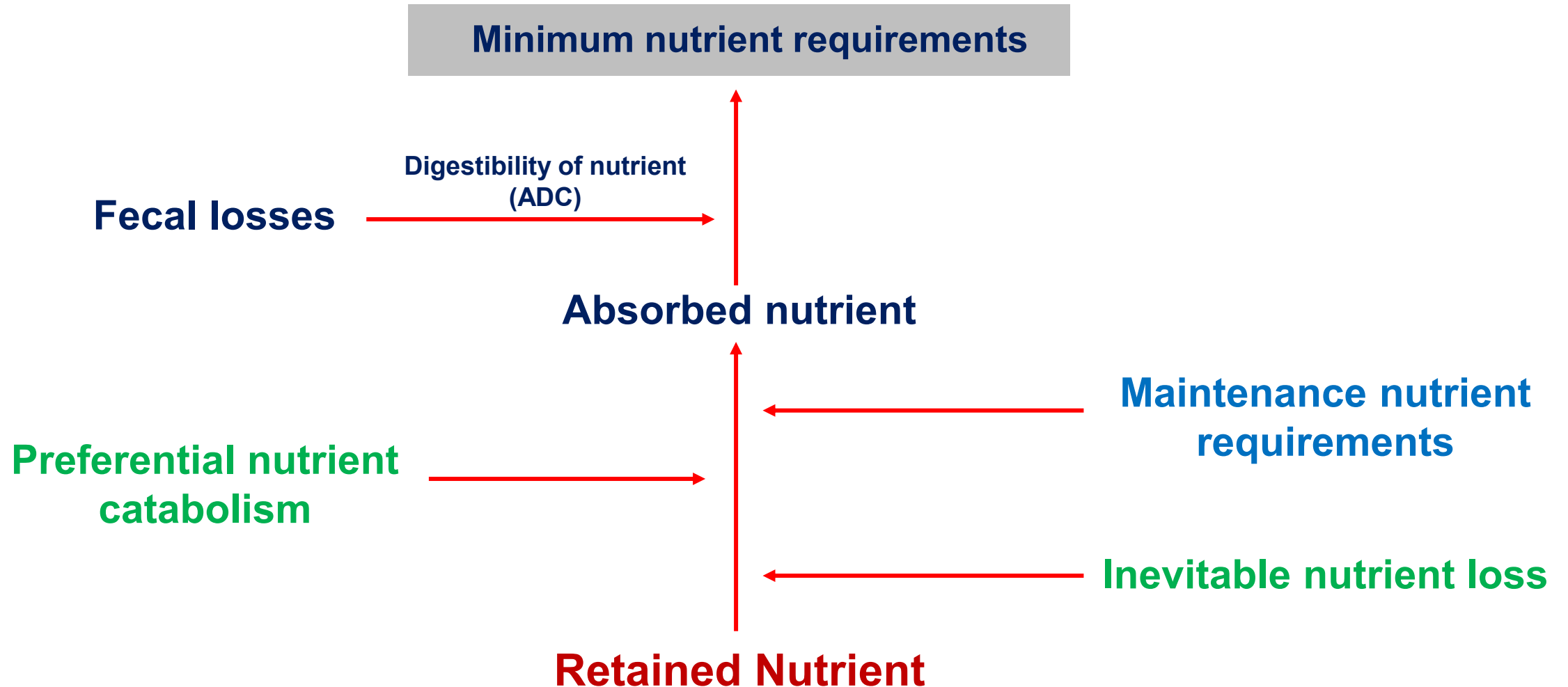
Empirical approach

- Generally estimated through feeding trials
- Often results in estimation of only one single value of requirement
- Costly and time consuming
- May be affected by several factors:
 - Weight of the animals
 - Composition of the experimental diet
 - Environmental conditions
 - Mathematical model used to estimate the requirement

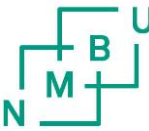


Estimation of nutritional requirements

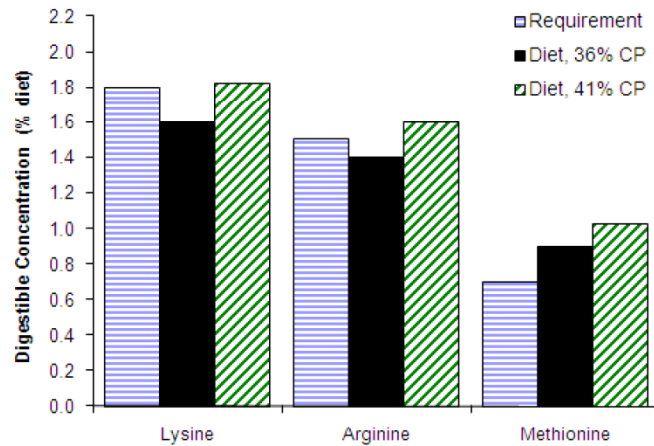
Factorial modelling approach



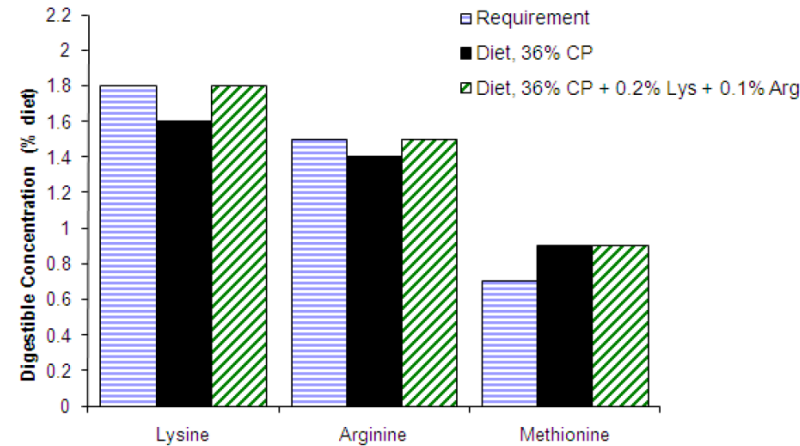
Strategies for meeting EAA requirements



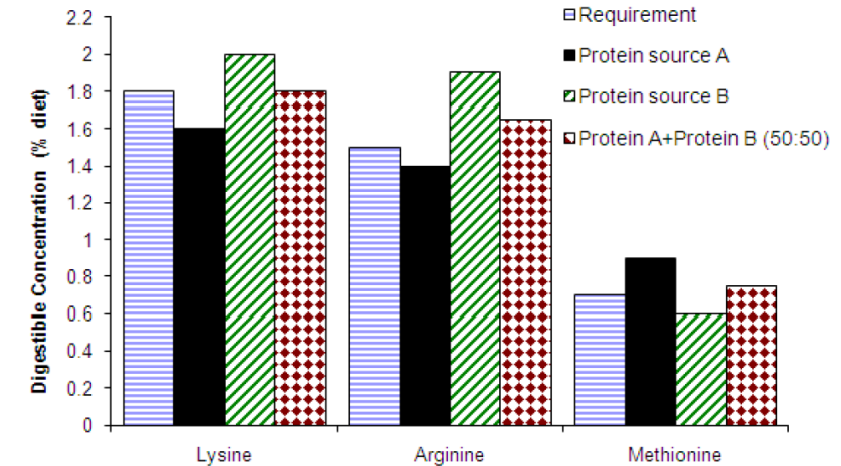
(1)



(2)



(3)



- (1) Increase total protein level of diet
- (2) Supplementation with crystalline amino acids
- (3) Use of a combination of different protein sources with different (complementary) amino acid profiles

Digestibility and feed formulation

- Increasing amount of information on the ADC of nutrients of different ingredients
- Digestibility of nutrients is an important aspect to consider in commercial feed formulation
- Feed manufacturers are progressively moving from formulating on a total nutrient basis to formulating on a digestible nutrient basis
- Tedious and costly to maintain R&D programs dedicated to digestibility of feed ingredients so manufacturers have to rely on published data or 3rd party estimates

Measuring digestibility in fish

- Indirect method
 - Use of digestion indicator (marker)=100 % indigestible
 - Collection of representative samples of fecal material produced

Apparent Digestibility Coefficient (ADC)= $1-(F/D \times Di/Fi)$

D=% nutrient (or KJ/g gross energy) of diet

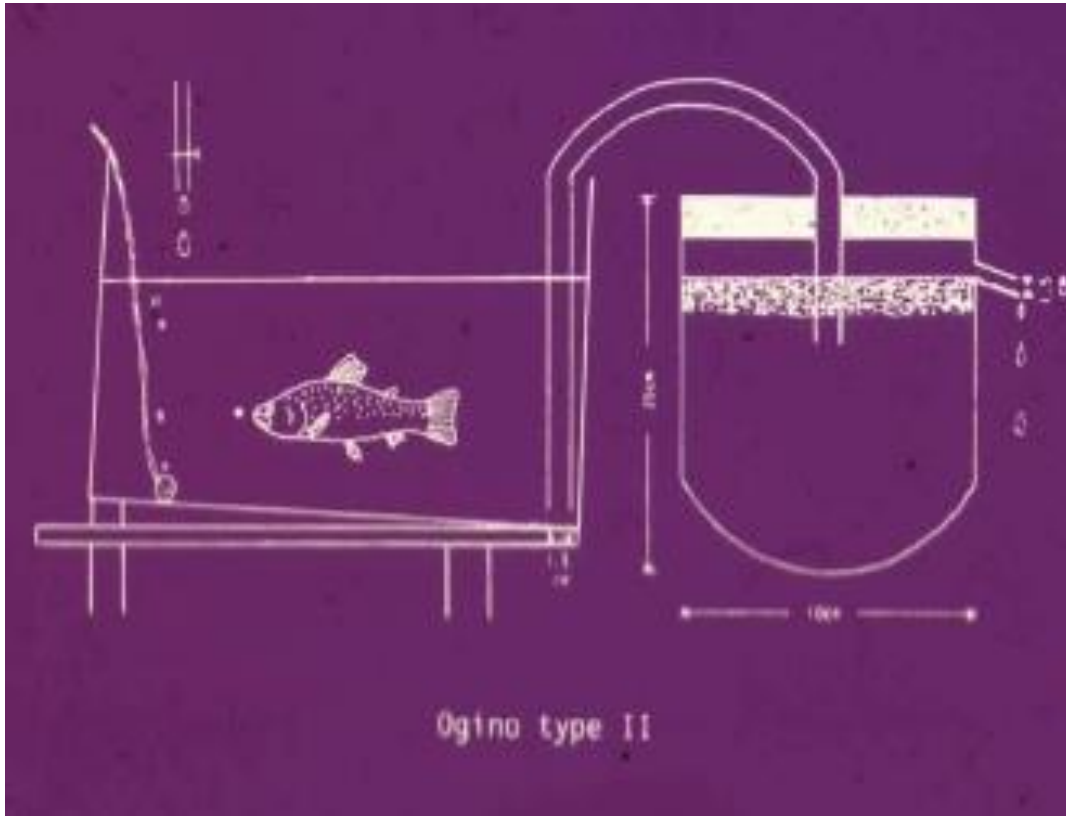
F=% nutrient (or KJ/g gross energy) of feces

Di=% digestion indicator of diet

Fi=% digestion indicator of feces

- Active collection methods:
 - E.g. stripping
- Passive collection methods:
 - E.g. TUF Column (Japan), St. Pee System (France), Guelph System (Canada)

Measuring digestibility in fish

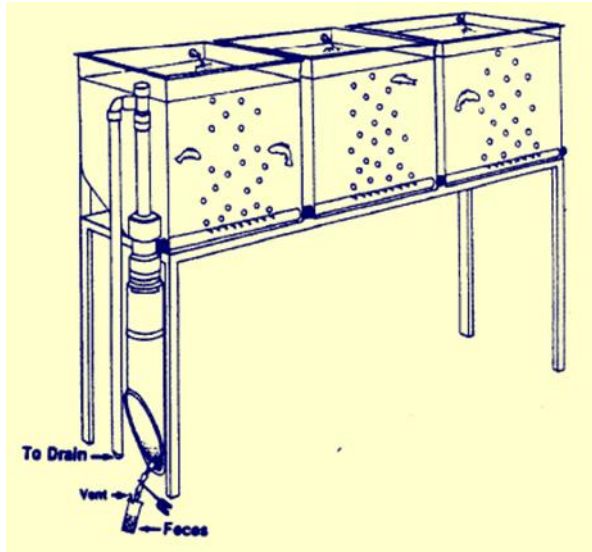


TUF column (Ogino et al., 1973)



St. Pee System (Choubert et al., 1979)

Measuring digestibility in fish



Guelph System (Cho et al., 1975)

Measuring digestibility in fish

- Most ingredients cannot be fed alone
 - Acceptance (palatability)
 - Pelletability
 - Nutritional quality

Ingredients	%
Fish meal, herring, 70% crude protein	25
Blood meal, porcine, spray-dried, 82% crude protein	11
Corn gluten meal, 60% crude protein	25
Wheat middlings, 17% crude protein	10
Corn, grain ground	10
Vitamin premix ^a (Martin Mills, PM1-83)	1
Mineral premix ^b (Martin Mills, 9504)	0.5
Di-calcium phosphate	0.5
Fish oil, herring	17
Total	100

	Diets			
	1 Ref	2 70%-Ref + 30%-IMC	3 70%-Ref + 30%-IMM	4 70%-Ref + 30%-SPC
<i>Proximate composition (as is)</i>				
Dry matter, %	95.7	94.5	96.3	96.6
Organic matter, %	89.7	87.7	89.9	89.8
Crude protein, %	50.5	52.7	48.2	52.6
Lipid, %	18.7	12.9	13.7	14.1
Total carbohydrate, %	20.5	22.1	28.0	23.1
NDF	7.6	8.9	10.7	7.3
ADF	3.8	5.5	6.7	4.3
Ash, %	6.0	6.8	6.4	6.8
Gross energy, kJ g ⁻¹	24.3	22.9	22.9	23.1
<i>Essential amino acids (% in the weight of diet as is)</i>				
Arginine	2.9	3.4	2.7	3.1
Histidine	1.9	1.8	1.5	1.6
Isoleucine	2.0	2.2	1.8	2.1
Leucine	6.7	5.9	5.2	5.8
Lysine	2.8	2.9	2.4	2.5
Phenylalanine	2.9	2.8	2.4	2.8
Threonine	1.9	2.0	1.7	1.8
Valine	3.5	3.3	2.8	3.1
<i>Phosphorus and phytate-P(as is)</i>				
Total phosphorus, %	1.0	1.2	1.1	1.0
Phytate-P, %	0.3	0.6	0.4	0.3

Ref—reference diet, IMC—Indian mustard protein concentrate, IMM—Indian mustard meal, and SPC—soy protein concentrate. Phytate-P is calculated as phytic acid × 0.282.

$$ADC_{\text{test ingredient}} = ADC_{\text{test diet}} + \left[(ADC_{\text{test diet}} - ADC_{\text{ref.diet}}) \times \left(0.7 \times D_{\text{ref}} / 0.3 \times D_{\text{ingr}} \right) \right]$$

Digestibility of nutrients in fish meals and PBM

Component	Fish meal		Poultry by-Products Meal		
	Herring	Menhaden	Feed-grade	Prime	Refined
	%				
Dry matter	81	71	71	72	75
Crude Protein	90	86	83	85	87
Crude fat	92	91	80	83	80
Phosphorus	58	47	49	46	56
Lysine	95	95	89	92	93
Methionine	95	95	92	95	94
Histidine	92	93	85	89	89
Threonine	90	92	82	85	85