Aquafeeds: Using Nutrient vs. Ingredient Specifications for Optimal Formulations

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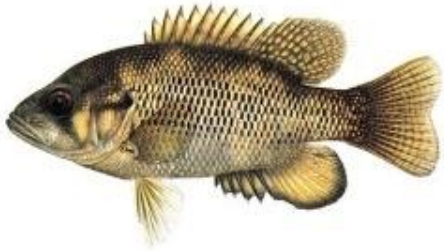
Feed Formulation

Definition: The process by which different feed ingredients are combined in proportions necessary to provide the animal with proper amount of nutrients needed at a particular stage of production, or to a nutritional profile meeting certain production objectives

- A “feed formula” is generally a list of ingredients to be mixed together
- Feeds are frequently sold on the basis of a proximate composition (32% CP tilapia feed)

Example of Formulation for Commercial Extruded Feed (32% CP) for Nile Tilapia in South-East Asia



Ingredients	%
Grains & tubers (corn, wheat, cassava, rice) + milling by-prod.	40
Soybean meal and other oilseeds (canola, sunflower, etc.)	35
Processed animal proteins (poultry meal, MBM, feather meal)	12
Functional ingredients (yeast, hydrolyzates, etc.)	5
Fish meal, local or imported	3
Soybean oil, lecithin, palm oil	2
Fish oil	1
Minerals, vitamins, amino acids and additives	2

Animals Utilize **NUTRIENTS**

not "**Ingredient**", "**Proximate Components**" and not "**Energy**"

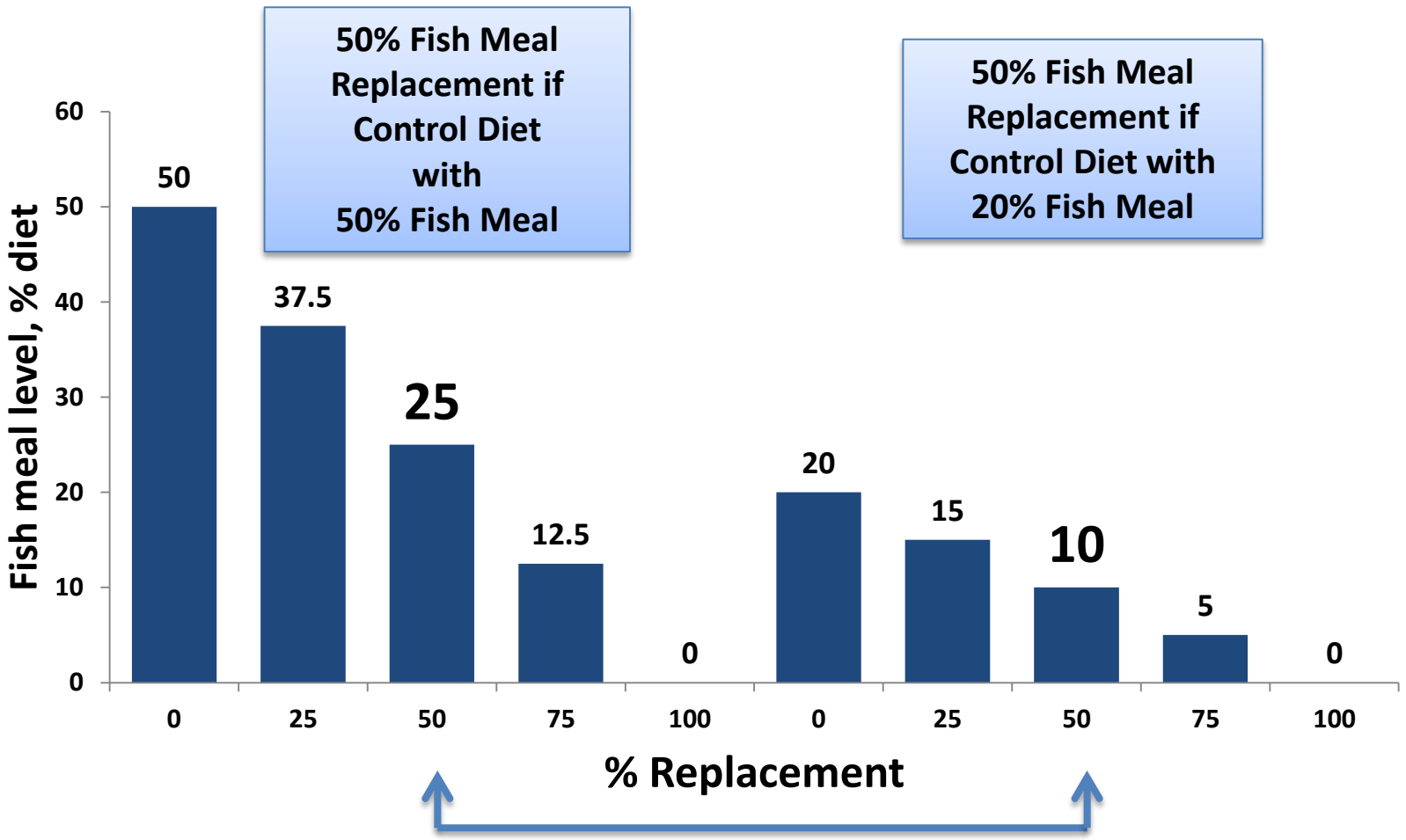
What's important in feed formulation?

- 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

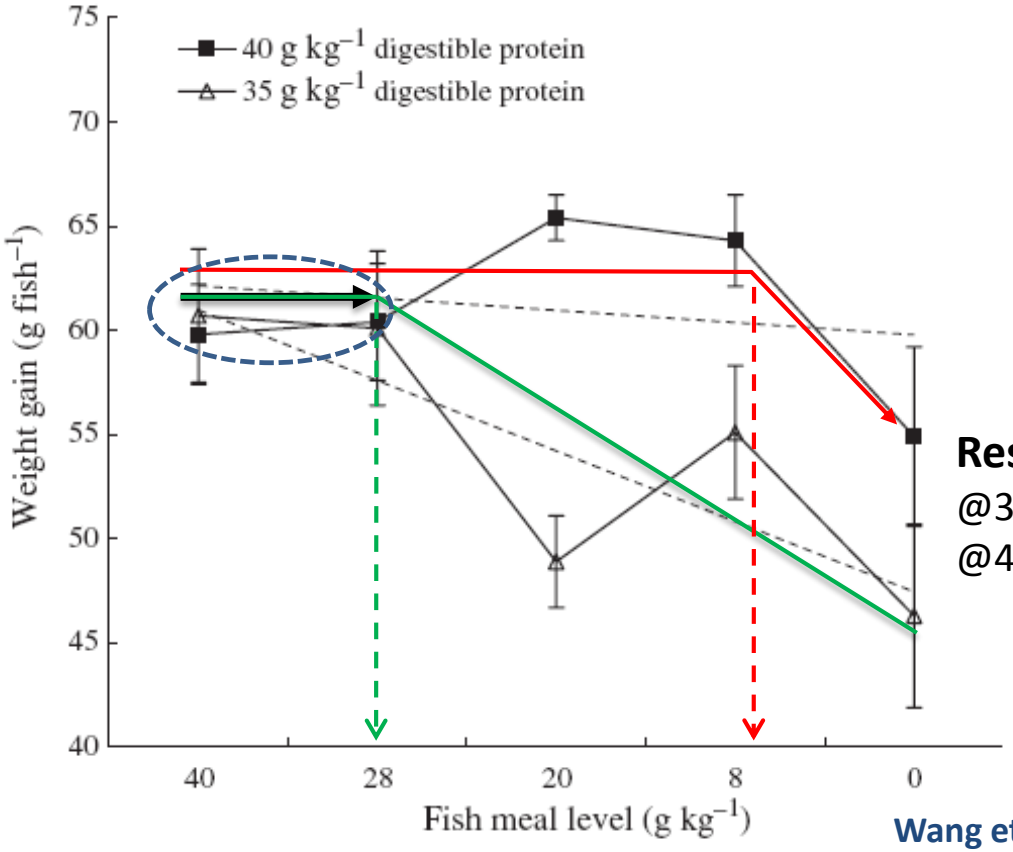
“Percent Replacement” is a Highly Relative Parameter!

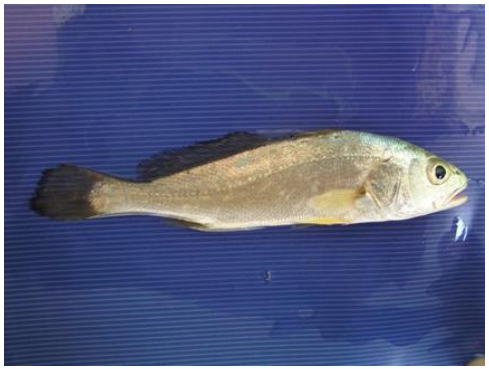
Ex: Replacing 25, 50, 75 and 100% of the fish meal of the diet

Let’s get rid of this terminology, please!



Effect of Replacement of Fish Meal by a Mixture of Animal Proteins in Marine Fish Feeds Formulated to Two Digestible Protein Levels





Results:

@35% digestible protein, need 28% fish meal

@40% digestible protein, need 7% fish meal

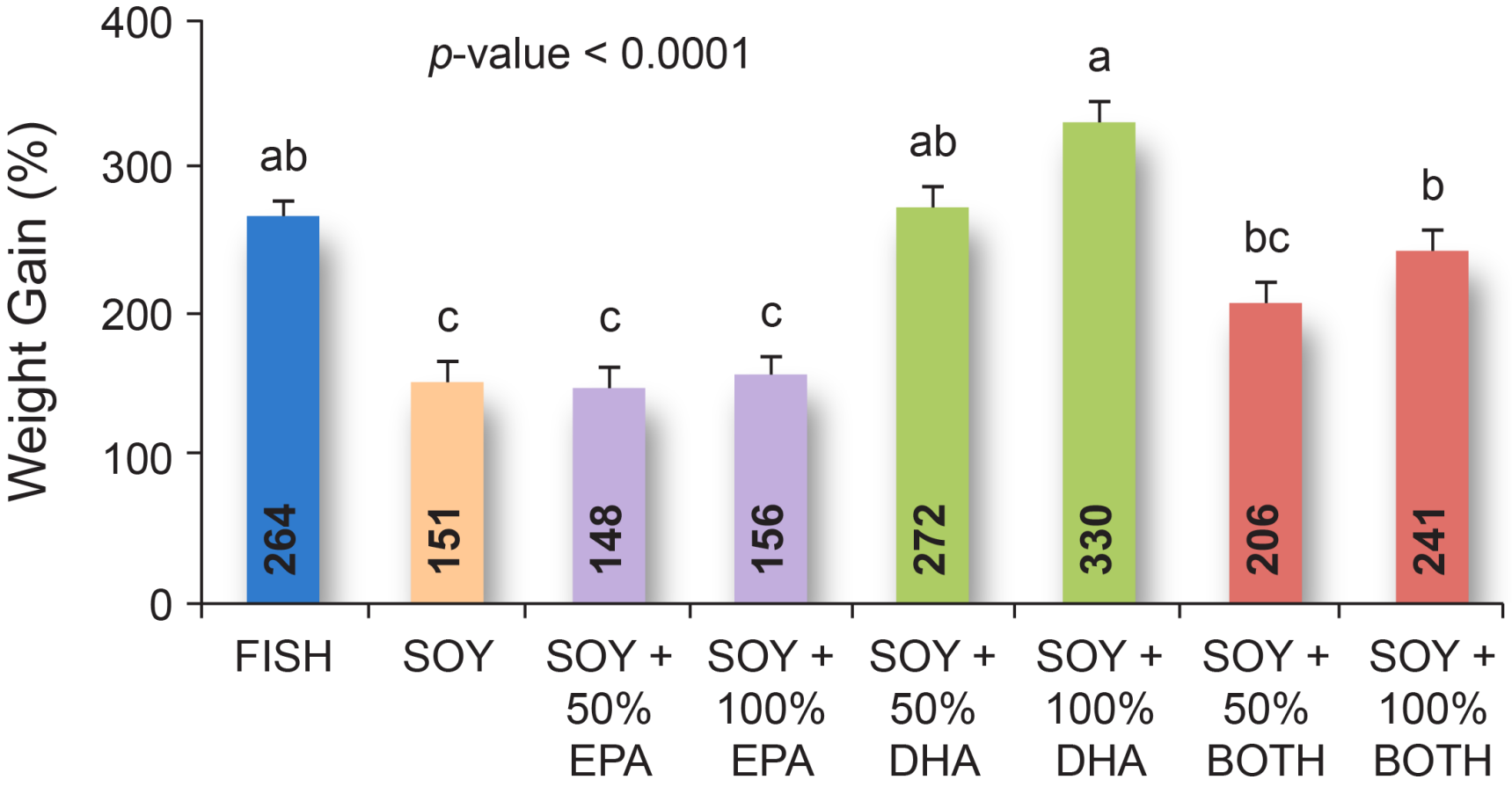
Wang et al. (2010)

Take home message:

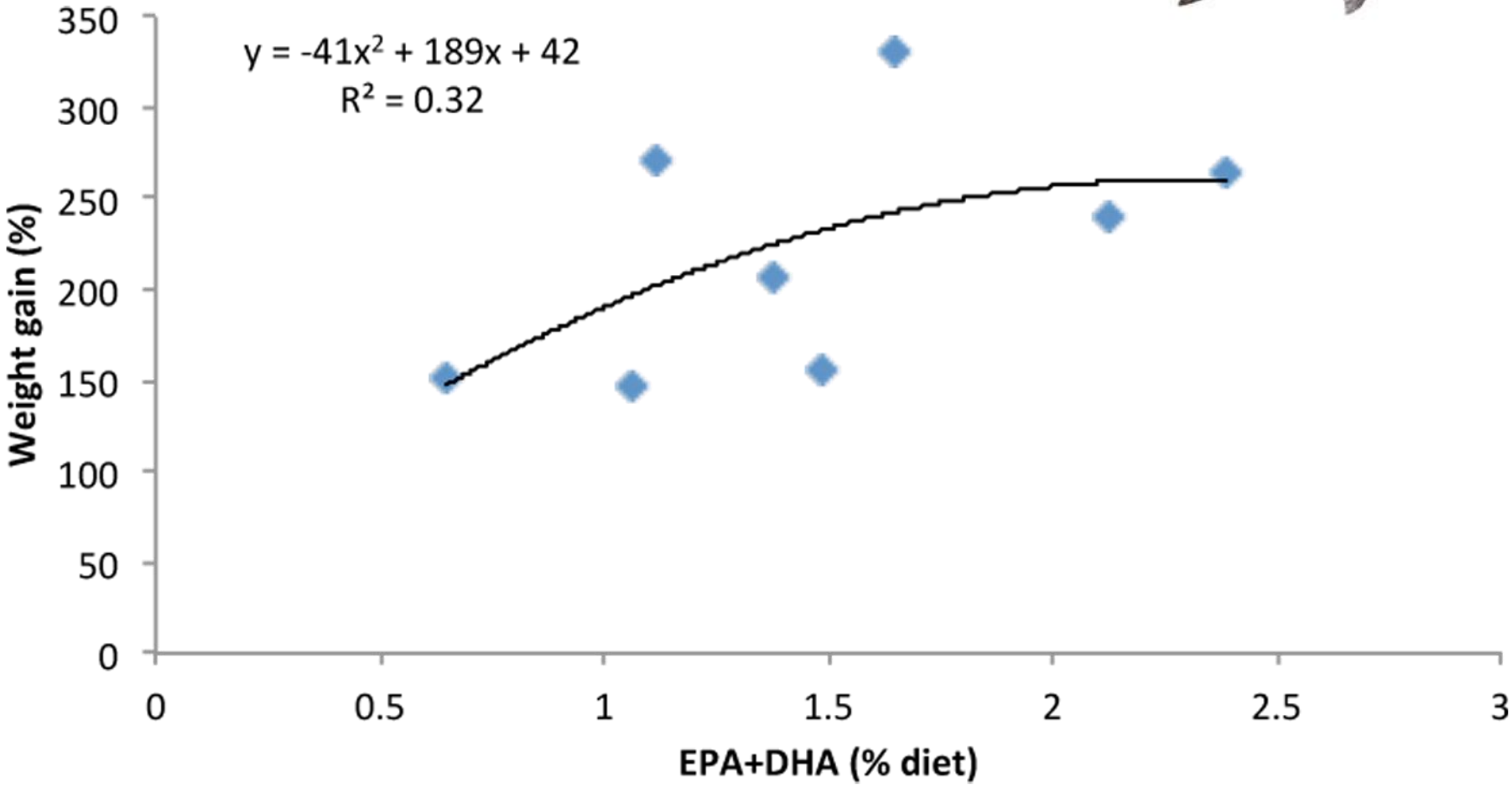
What matters is not fish meal level but meeting the essential amino acids (EAA) requirement of the animal!!!

Yes, a small amount of fish meal was still essential to maintain performance because it is a source of other nutrients (poorly characterized).

Fish Oil Replacement in Cobia

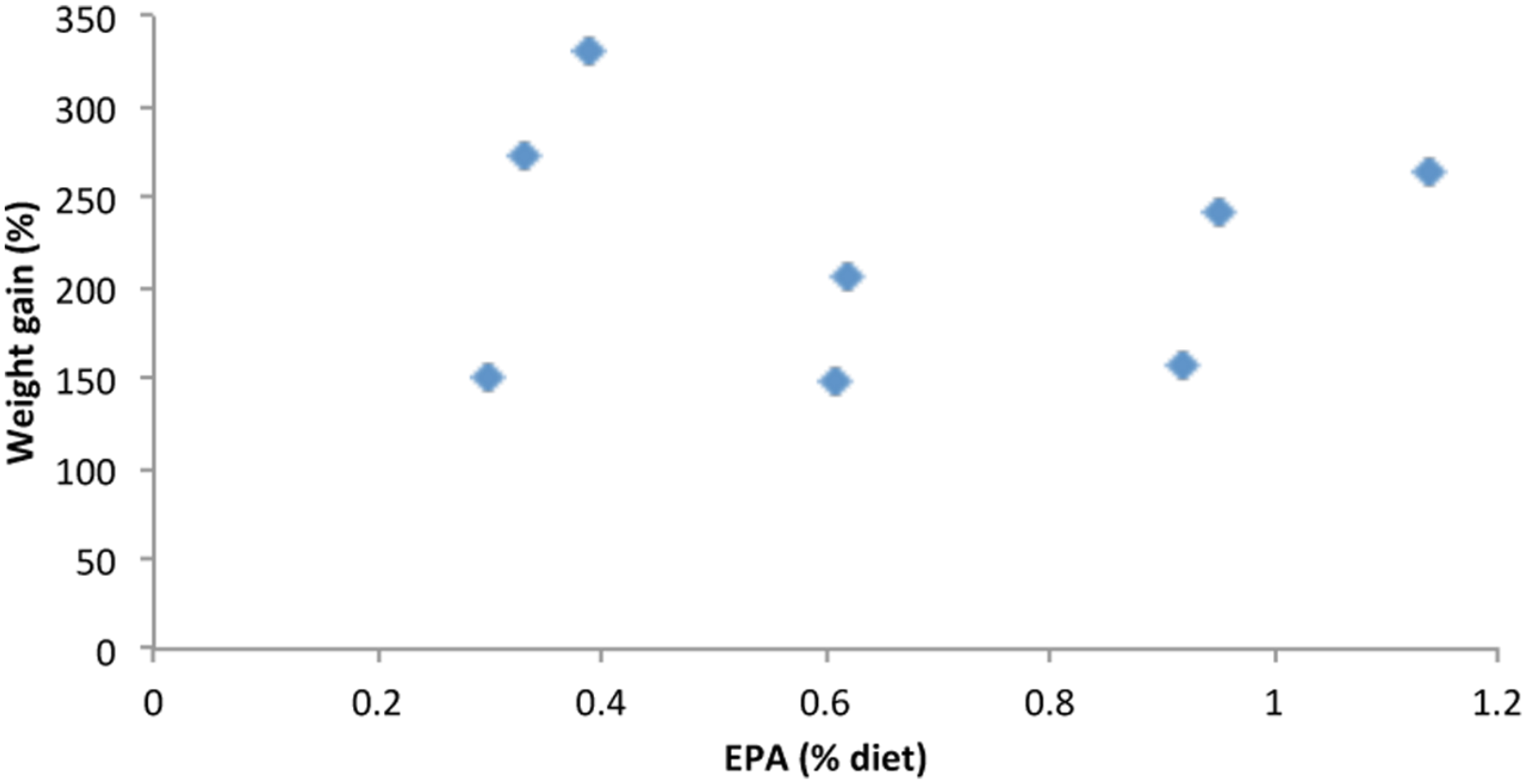


Trushenski et al. (2012)



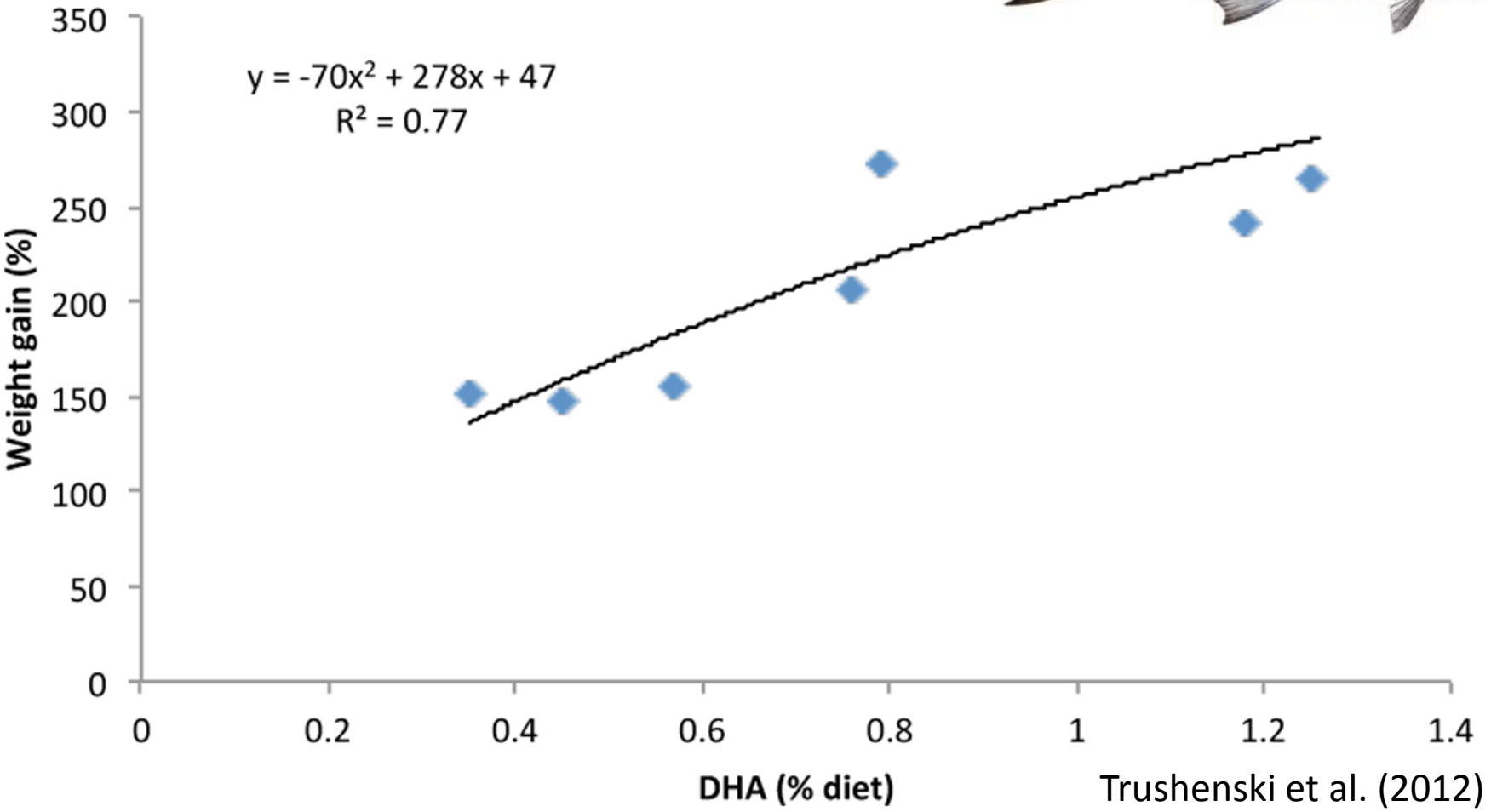
In Cobia, the response of the fish to EPA+DHA is not robust

Trushenski et al. (2012)



Cobia does not appear to respond to EPA !

Trushenski et al. (2012)



Trushenski et al. (2012)

Cobia responds well to the level of DHA only !

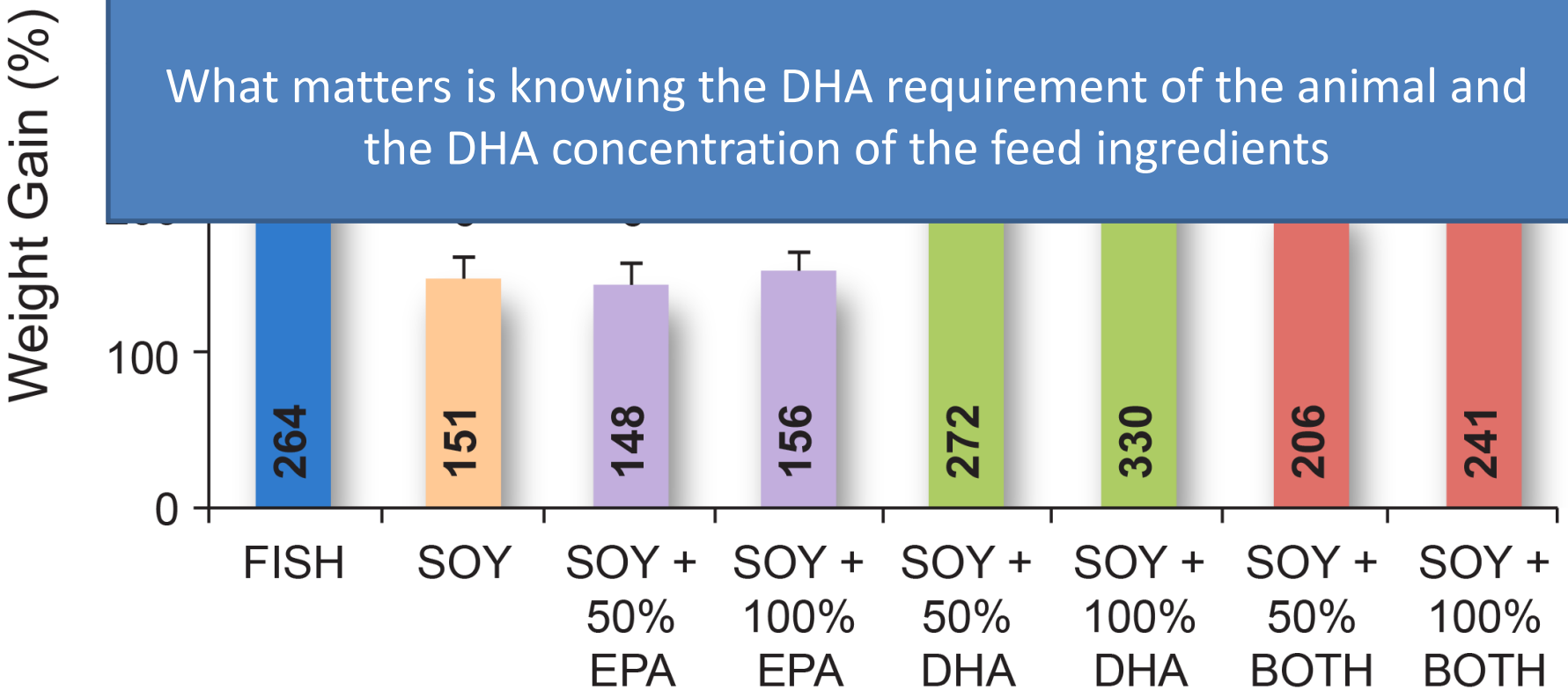
DHA is the essential nutrient and what matters!

Fish Oil Replacement in Cobia

The Issue is not Fish Oil vs. Soy Oil

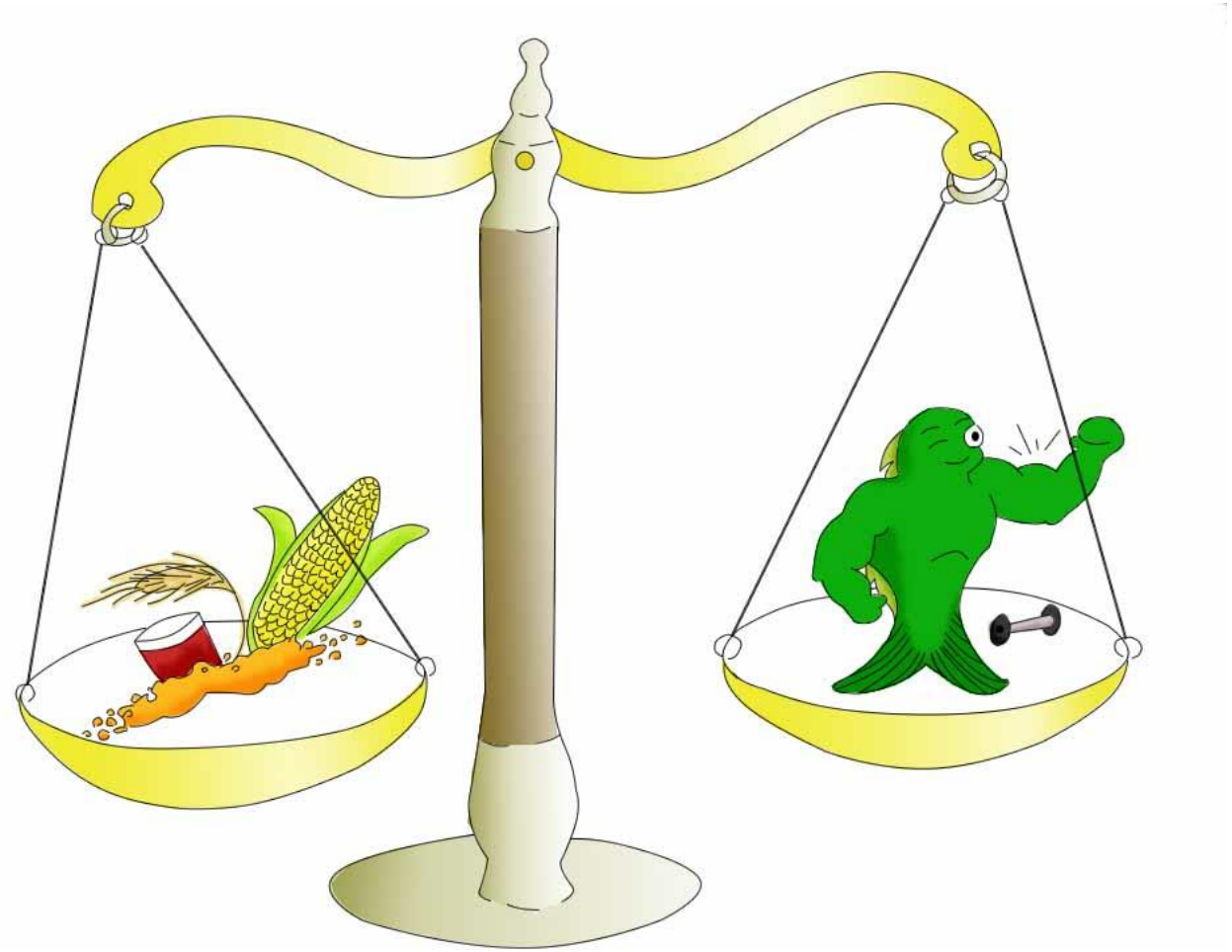
The issue is meeting the specific nutrient (DHA) requirement of the fish using an effective source of DHA!

What matters is knowing the DHA requirement of the animal and the DHA concentration of the feed ingredients



Trushenski et al. (2012)

Animal Nutrition = Balanced Understanding of Nutritional Requirements and Ingredient Quality



You can't disconnect nutritive value of ingredients and nutritional requirements of the animal

Animals Utilize **NUTRIENTS**

not "Proximate Components" , not "Ingredients", and not "Energy"

What's important?

- Individual nutrient requirements of animals
- 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

Generic names often regroup ingredients that can be widely different. Not buying a "name"

Nutrient Composition of Different Fish Meals and Poultry by-Products Meals

	Fish meal		Poultry by-Products Meal		
Composition	**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

Cheng and Hardy (2002)

Tools / Techniques Available to the Feed Industry?

Left: A Unity Scientific SpectraStar 2400 NIRS machine prepared to analyze barley. Below: A spectral fingerprint from an analysis performed by an NIRS machine.

Table 1. Nutrient compositions of 4 soybean meals estimated by NIRS

SBM source	India	Argentina	USA	Malaysia
Moisture (%)	10.44	10.61	10.66	11.13
Fat (%)	1.36	2.12	2.63	2.55
Crude fiber (%)	6.05	3.75	3.94	2.28
Ash (%)	8.04	6.81	6.22	5.54
ME (kcal/kg)	2162	2340	2376	2550
Protein (%)	46.0	46.5	47.5	47.5
Dig. Lys (%)	2.36	2.43	2.46	2.69
Dig. Met (%)	0.55	0.57	0.56	0.59
Dig. M+C (%)	1.03	1.12	1.13	1.18
Dig. Trp (%)	0.56	0.59	0.60	0.64
Dig. Thr (%)	1.56	1.64	1.61	1.75
Dig. Arg (%)	3.06	3.16	3.10	3.39

Where do these digestible amino acid calibrations come from? How reliable are they? Be careful.

Apparent Digestibility of Nutrients of Different Fish Meals and Poultry By-Products Meals

	Fish meal		Poultry by-Products Meal		
Component	**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

Different ingredients from the same generic categories differ in digestibility.

Cheng and Hardy (2002)

Blood Meal

Guelph System	ADC	
	Protein	Energy
Spray-dried blood meal	96-99%	92-99%
Ring-dried blood meal	85-88%	86-88%
Steam-tube dried blood meal	84%	79%
Rotoplate dried blood meal	82%	82%

Bureau et al. (1999)

Different drying equipments can greatly affect apparent digestibility

Estimates of Apparent Digestibility Coefficient of Processed Animal Proteins

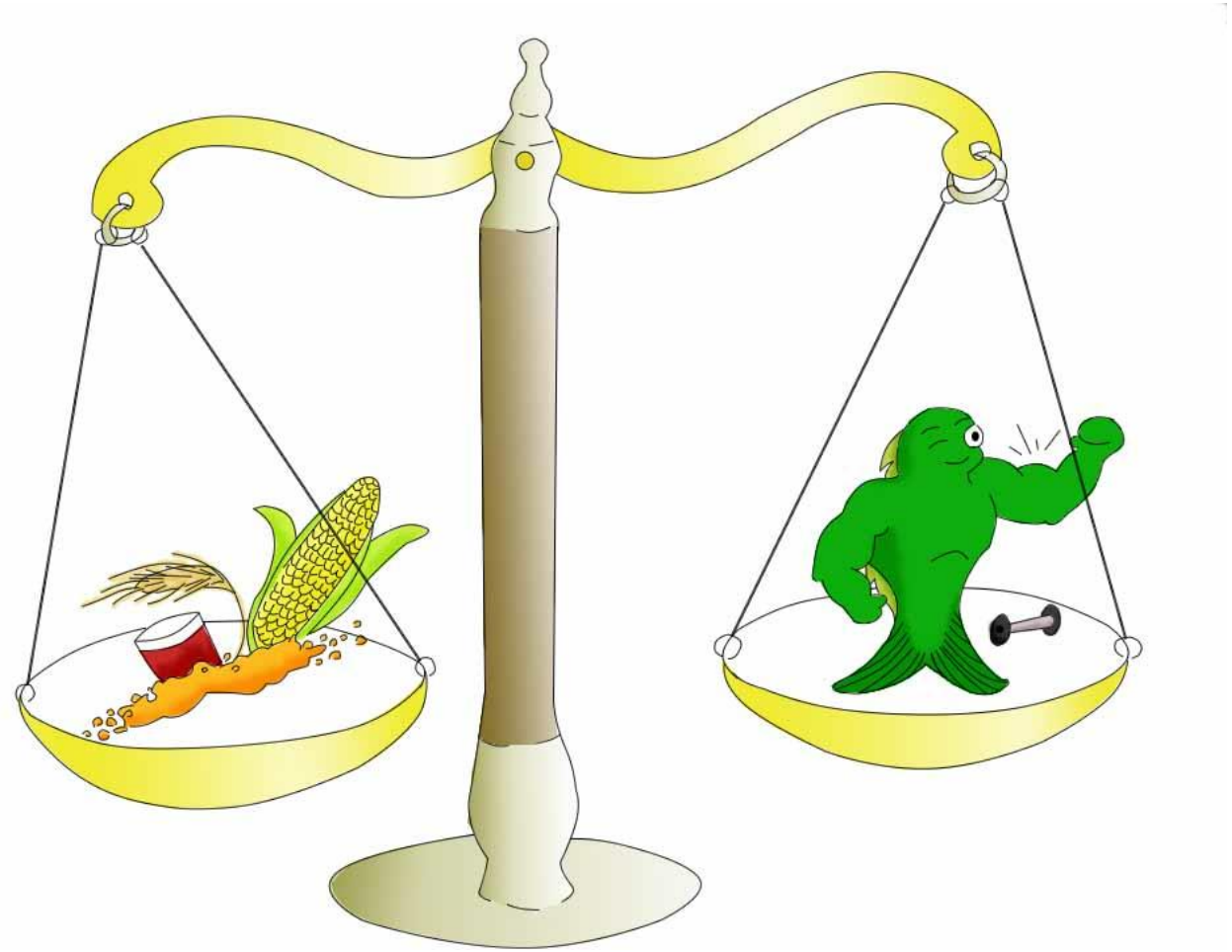
Ingredients	Apparent Digestibility Coefficients (%) DM	CP	GE
Trial #1			
Feather meal 1	82	81	80
Feather meal 2	80	81	78
Feather meal 3	79	81	76
Feather meal 4	84	87	80
Meat and bone meal 1	61	83	68
Meat and bone meal 2	72	87	73
Feather meal 5	82	86	82
Feather meal 6	83	86	81
Feather meal 7	83	88	83
Meat and bone meal 7	78	92	86
Meat and bone meal 8	72	89	81
Meat and bone meal 9	69	88	80

Recommendation:

Be highly skeptical
Make sure data are logical / adding up
Adopt “conservative” (low) estimates of ADC

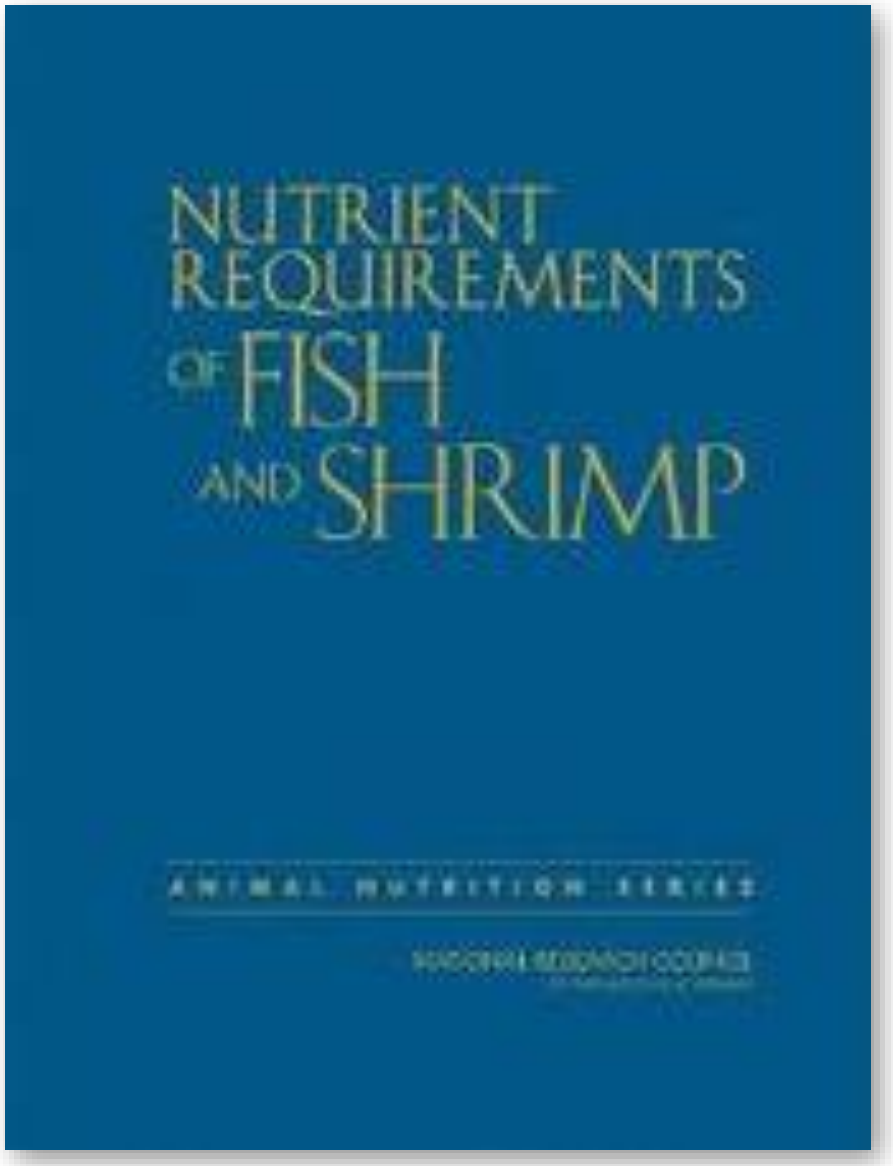
76
82
83
84

Animal Nutrition = Balanced Understanding of Nutritional Requirements and Ingredient Quality



You can't disconnect nutritive value of ingredients and nutritional requirements of the animal

NRC Nutrient Requirements of Fish and Shrimp (2009-2011)



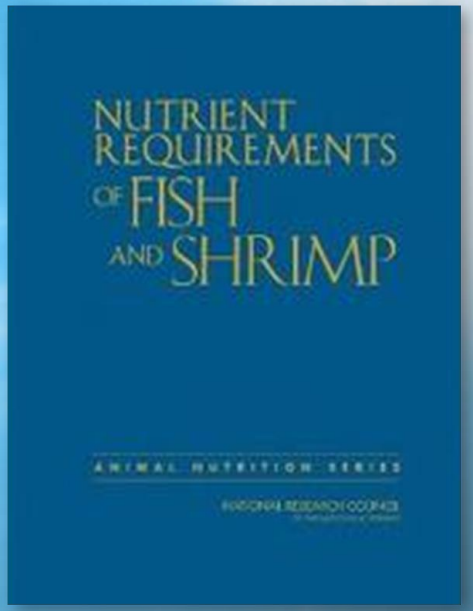
NRC 2011

Review of state-of-the-art

Committee reviewed 1000s of papers

Imperfect document and recommendations represent best effort

What Do Fish and Shrimp Require?



Traditional

Traditional Essential Nutrients:

Same for all species:

10 Essential amino acids
Fat and water soluble vitamins
Vitamin-like compounds (choline, *myo*-inositol)
Minerals

Nutrients with some aspects of essentiality that are species and life stage-specific:

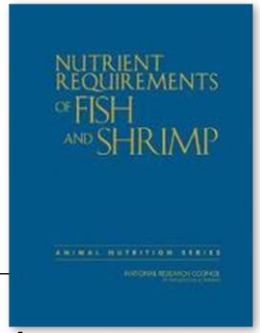
Essential fatty acids ω-3, ω-6

Novel

Nutrients for which essentiality is species and stage-specific:

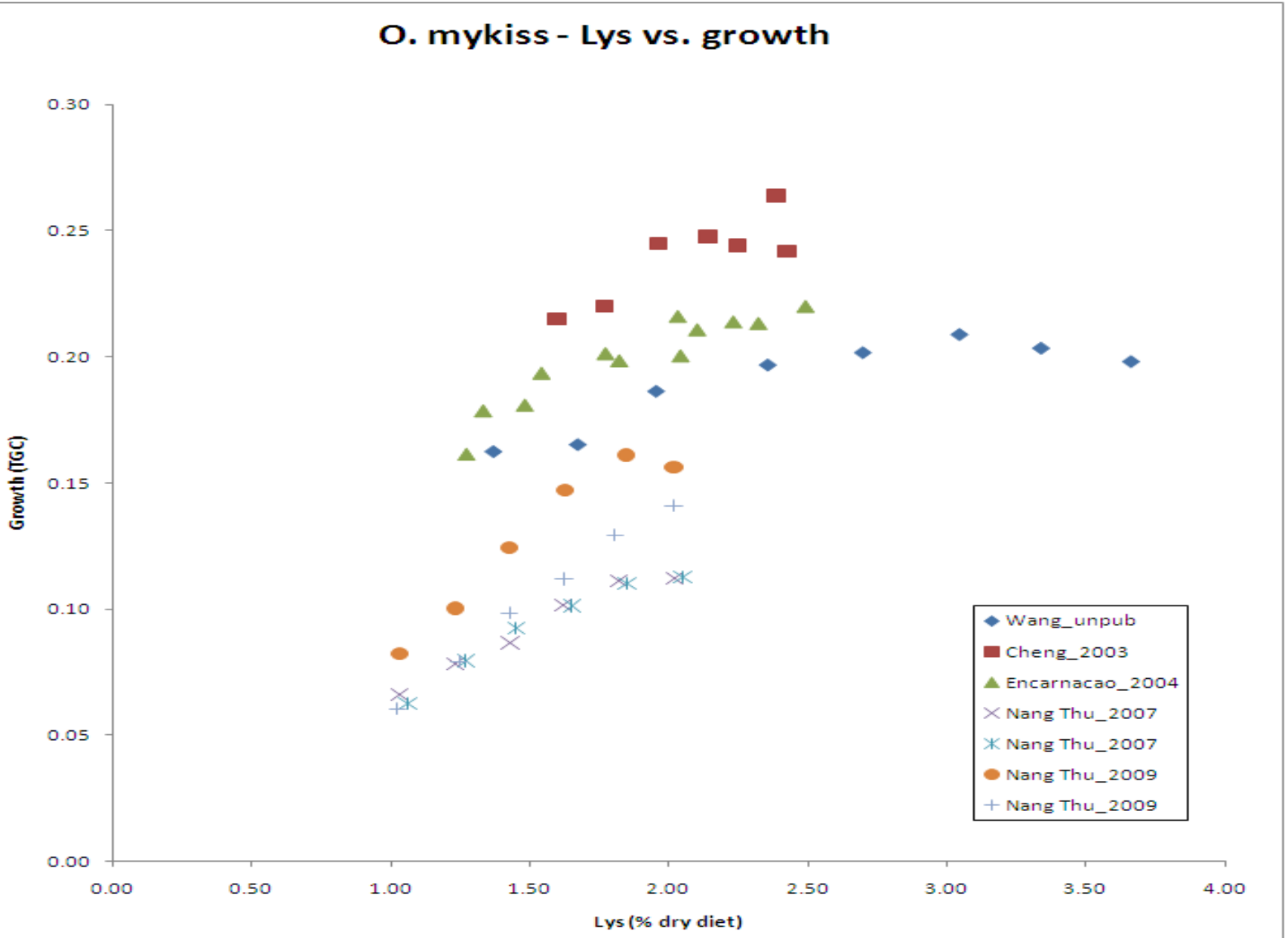
Taurine
Phospholipids (a very wide class of chemicals)
Cholesterol ?
Nucleotides ?
Other compounds?

NRC (2011) Essential Amino Acid Requirements of Different Fish Species ("Juvenile" Stage)



Amino Acids	Atlantic Salmon	Common Carp	Nile Tilapia	Channel catfish	Rainbow Trout	Asian Seabass	European Seabass	Japanese Flounder	Red Drum	Yellowtail
Arginine	1.8	**1.7**	1.2	1.2	1.5	1.8	1.8	2.0	1.8	1.6
Histidine	0.8	0.5	**1.0**	0.6	**0.8**	NT	NT	NT	NT	NT
Isoleucine	1.1	**1.0**	**1.0**	0.8	**1.1**	NT	NT	NT	NT	NT
Leucine	1.5	1.4	1.9	1.3	1.5	NT	NT	NT	NT	NT
Lysine	2.4	**2.2**	**1.6**	1.6	**2.4**	2.1	2.2	2.6	1.7	1.9
Methionine	0.7	0.7	0.7	0.6	0.7	0.8	NT	0.9	0.8	0.8
Met+Cys	1.1	1.0	1.0	1.0	1.1	1.2	1.1	NT	1.2	1.2
Phenylalanine	0.9	1.3	1.1	0.7	0.9	NT	NT	NT	NT	NT
Phe+Tyr	1.8	2.0	1.6	1.6	1.8	NT	NT	NT	NT	NT
Threonine	1.1	**1.5**	1.1	0.7	**1.1**	NT	1.2	NT	0.8	NT
Tryptophan	0.3	0.3	0.3	0.2	0.3	NT	0.3	NT	NT	NT
Valine	1.2	**1.4**	**1.5**	0.8	1.2	NT	NT	NT	NT	NT
Taurine	NR	NR	NT	NR	NR	R	0.2	R	R	R

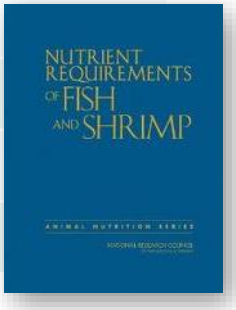
Take home: We have reasonably good estimates for many species. Still major gaps.



Estimating Essential Nutrient Requirements Across Studies is not Simple. Reference values are not always very robust.

Essential Amino Acid Requirements of Shrimp Species

Nutrient	Rainbow Trout	Kuruma prawn	Tiger shrimp	Pacific white legged shrimp
	% diet	*Marsupenaeus japonicus*	*Penaeus monodon*	*Litopenaeus vannamei*
Arginine	1.5	1.6	1.9	
Histidine	0.8	0.6	0.8	
Isoleucine	1.1	1.3	1.0	
Leucine	1.5	1.9	1.7	
Lysine	2.4	1.9	2.1	1.6
Methionine	0.7	0.7	0.7	
Met+Cys	1.1	1.0	1.0	
Phenylalanine	0.9	1.5	1.4	
Phe+ Tyr	1.8	R	R	
Threonine	1.1	1.3	1.4	
Tryptophan	0.3	0.4	0.2	
Valine	1.2	1.4	R	

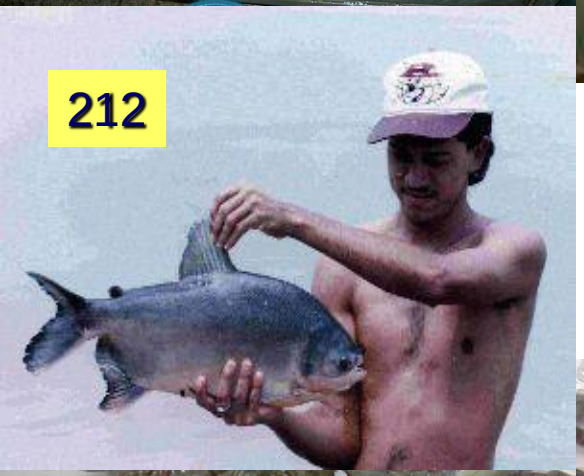


NRC (2011)

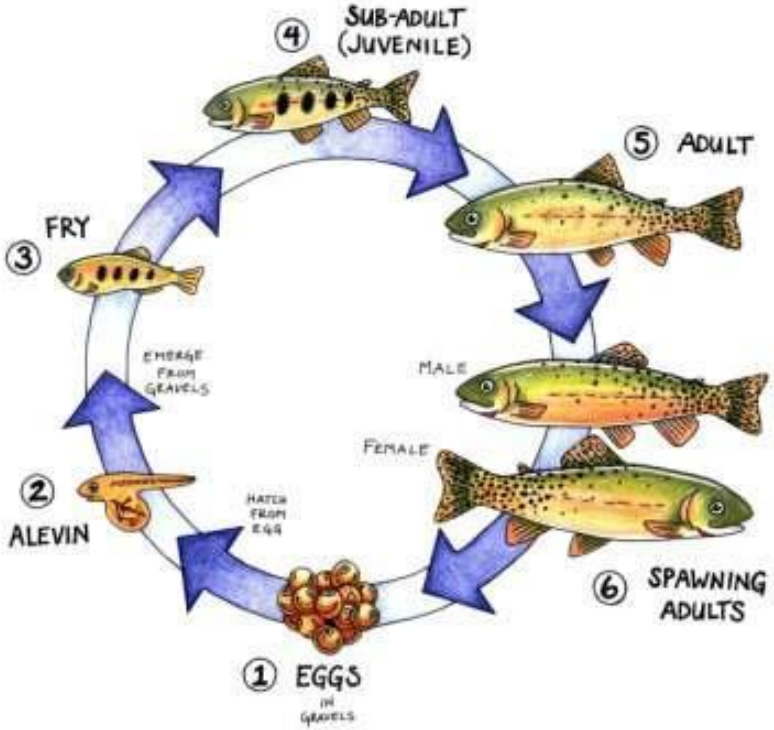
Current Challenge:

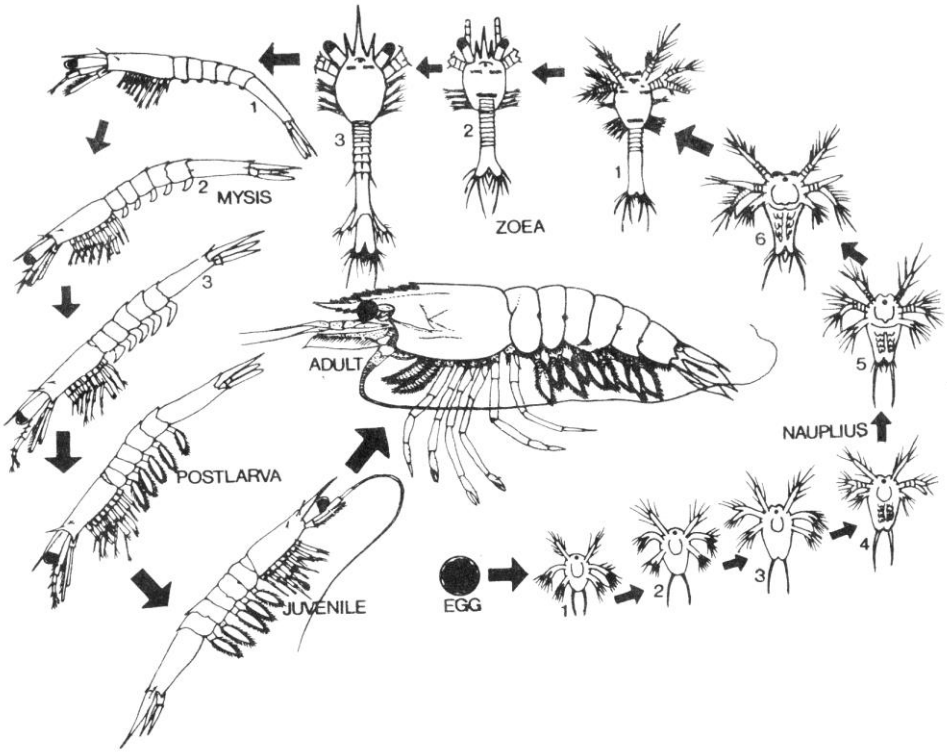
Developing Nutritional Specifications for Different Species, Life Stages, Weight Ranges and Feed Types

AQUACULTURE = Diversity of Species



Slide courtesy of Dr. A.J. Tacon


4 SUB-ADULT (JUVENILE)
5 ADULT
FRY
3
EMERGE FROM GRAVELS
MALE
FEMALE
2
ALEVIN
HATCH FROM EGG
6 SPAWNING ADULTS
1 EGGS IN GRAVELS

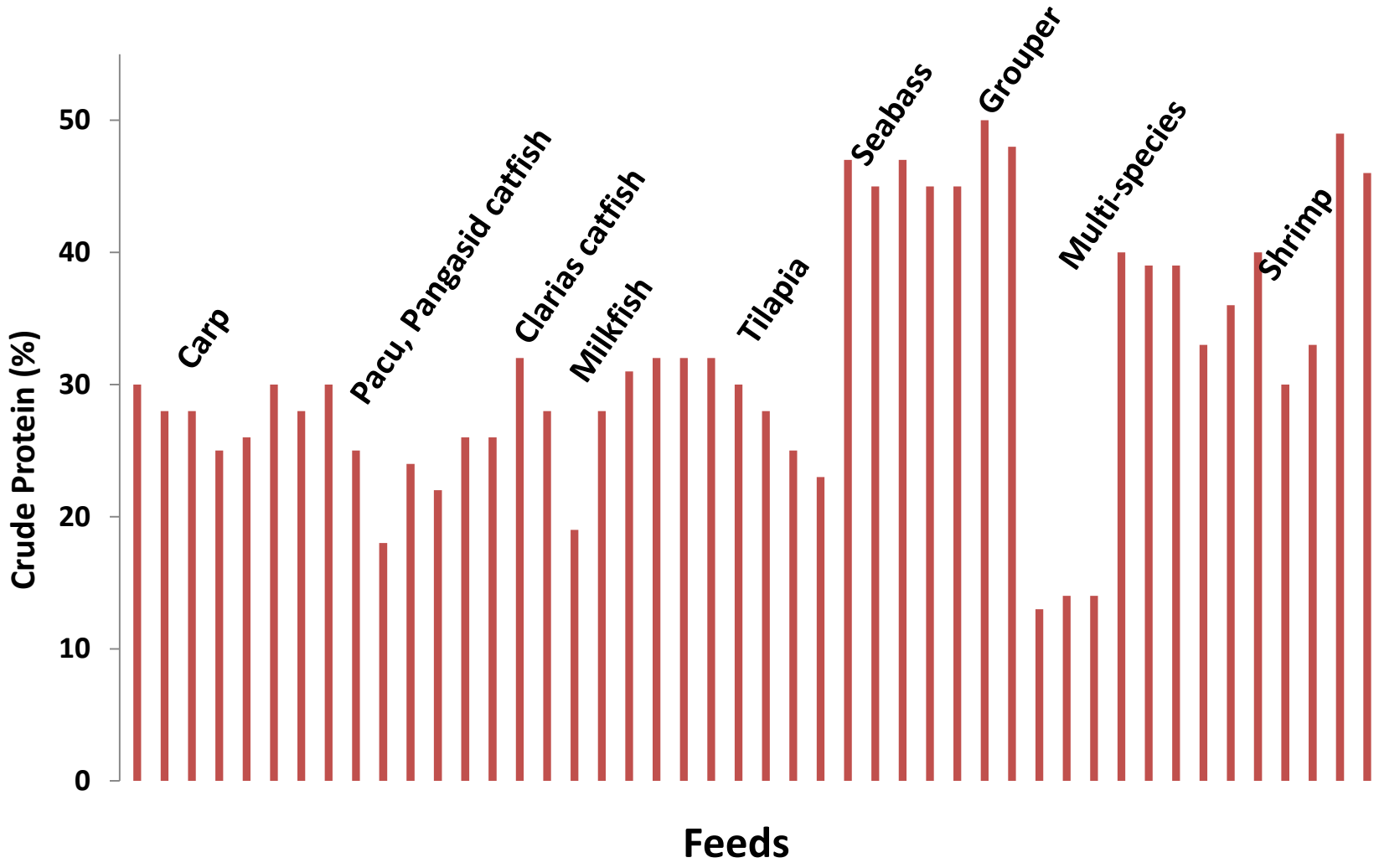

1
2
MYSIS
3
POSTLARVA
JUVENILE
ADULT
3
2
ZOEA
1
6
5
NAUPLIUS
4
EGG
1
2
3

Feed is not “Feed”

Atlantic salmon (Azevedo, 1998)

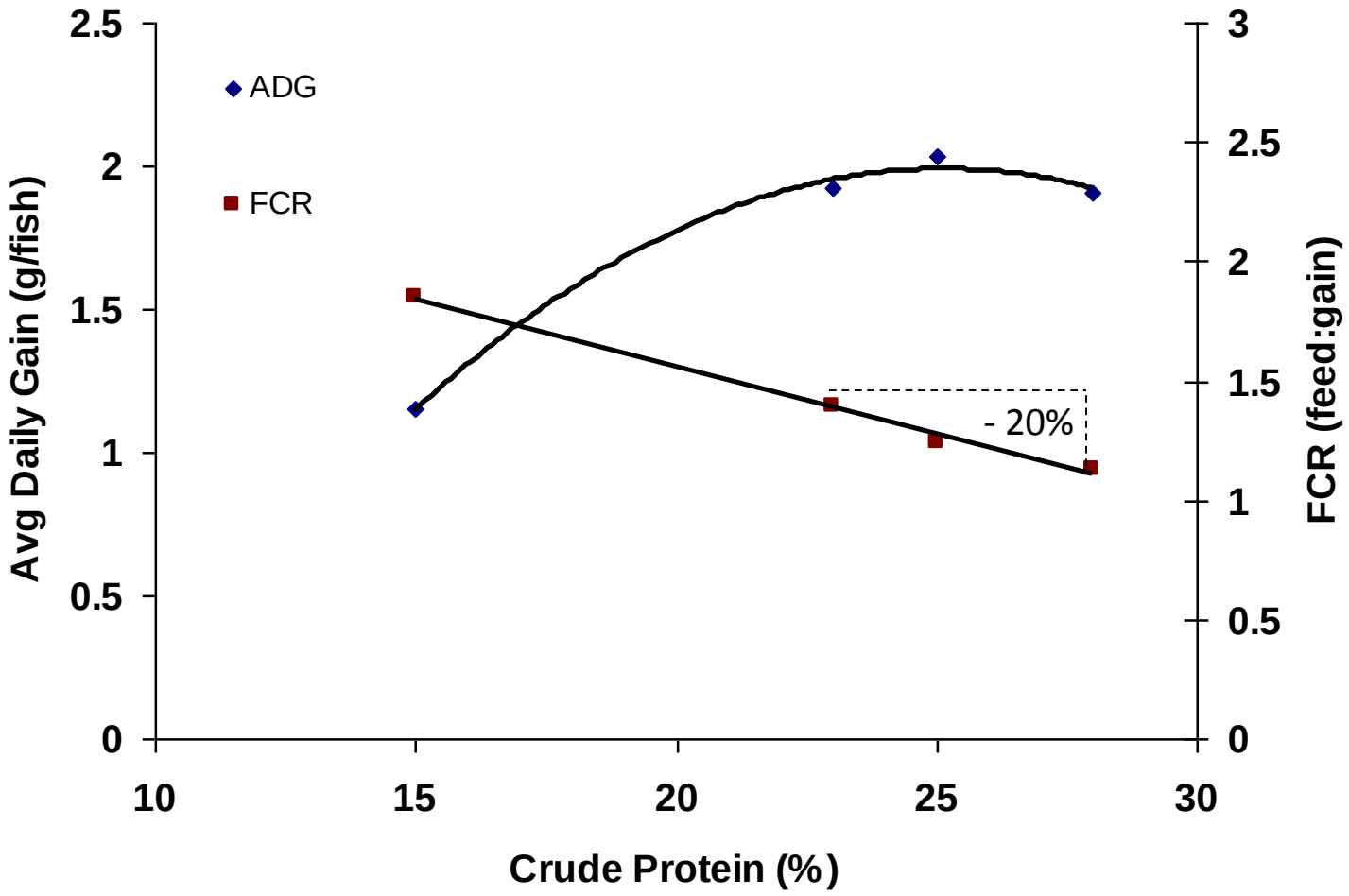
	Regular	HND
DP, %	37	44
DE, MJ/kg	18	22
DP/DE, g/MJ	20	20
Weight gain, g/fish	33.4	33.6
Feed efficiency, G:F	1.09	1.33
FCR, F:G	0.92	0.75

Protein Levels of Aquaculture Feeds Produced by a “Generalist” Aquaculture Feed Manufacturer



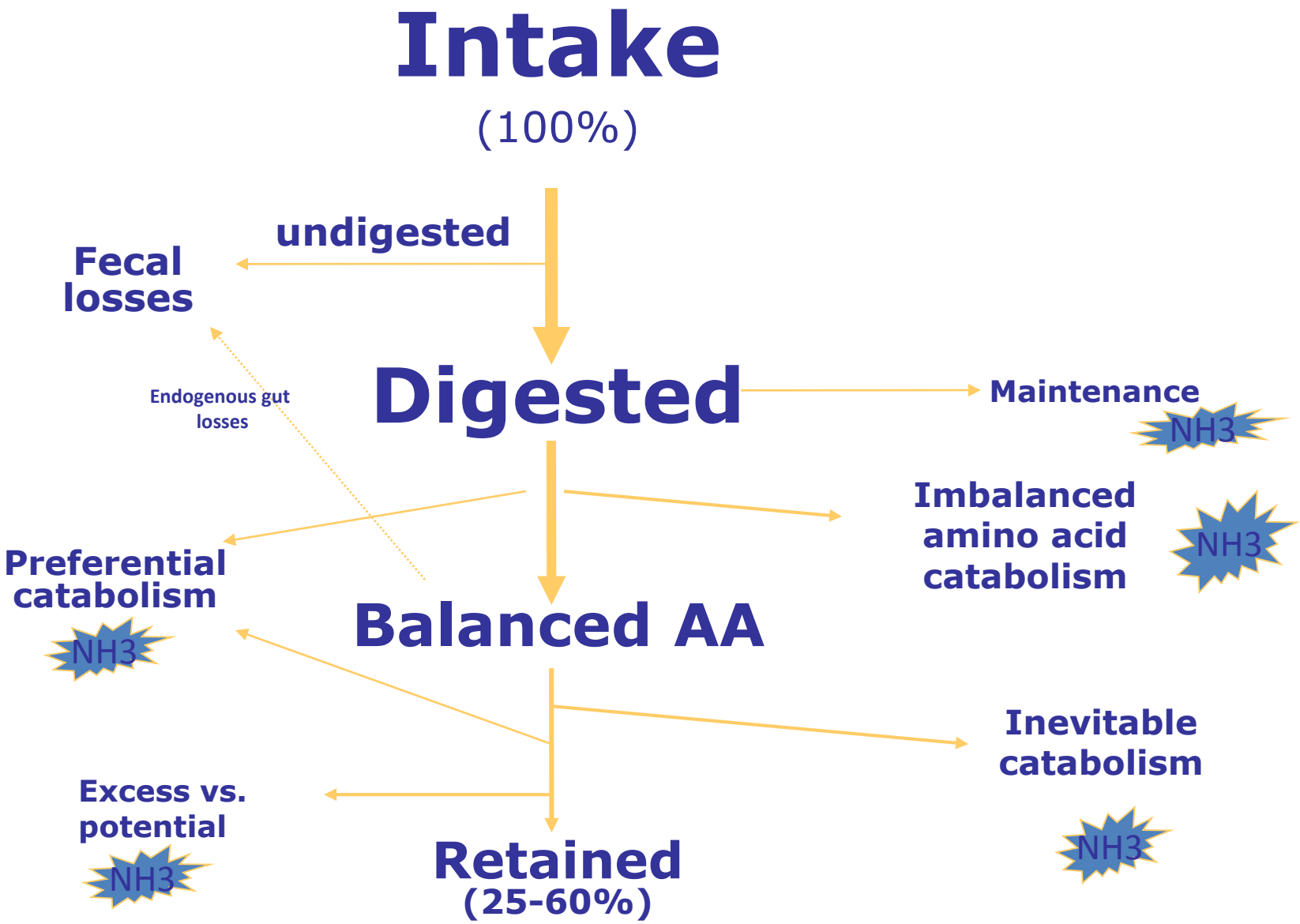
How you adapt the nutrient composition of feed of different chemical composition?
Multiple contradictory opinions / approaches

Daily Weight Gain and Feed Conversion Ratio of Nile Tilapia Fed Commercial Feeds with Different Nutrient Densities

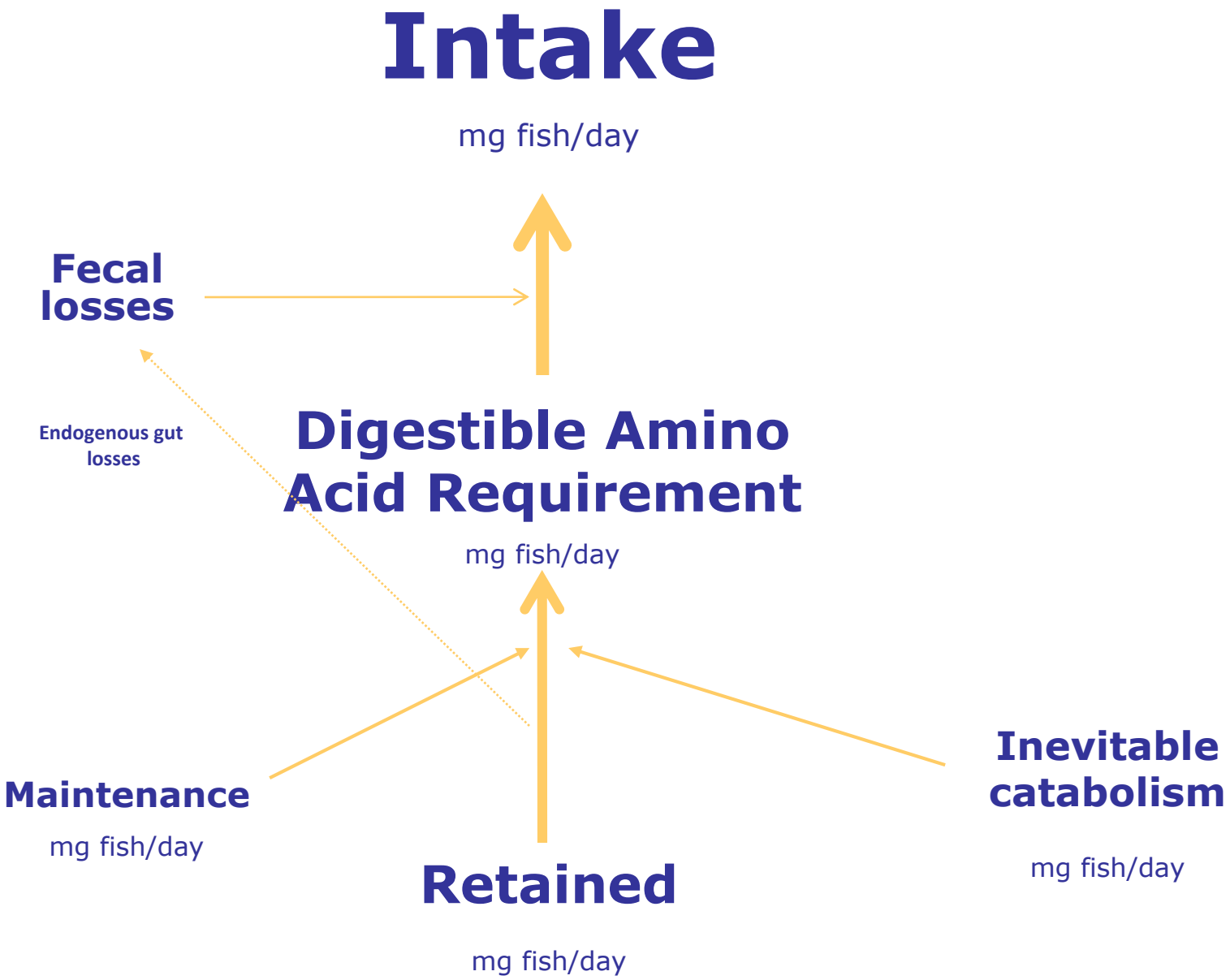


Data from a commercial cage culture operation in SE Asia

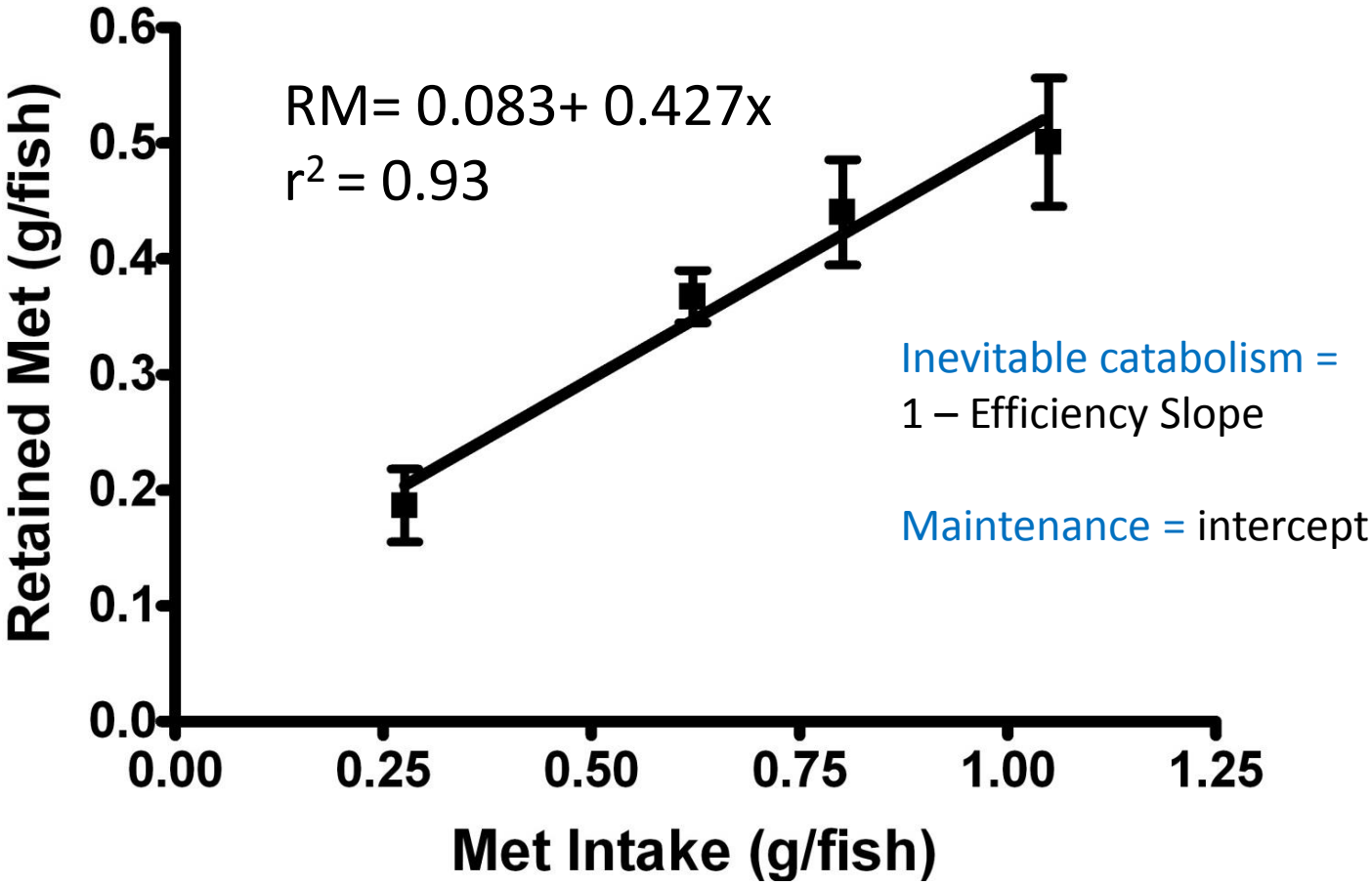
Factorial Amino Acid Utilization Scheme



Factorial Amino Acid Requirement Model



Efficiency of Retention

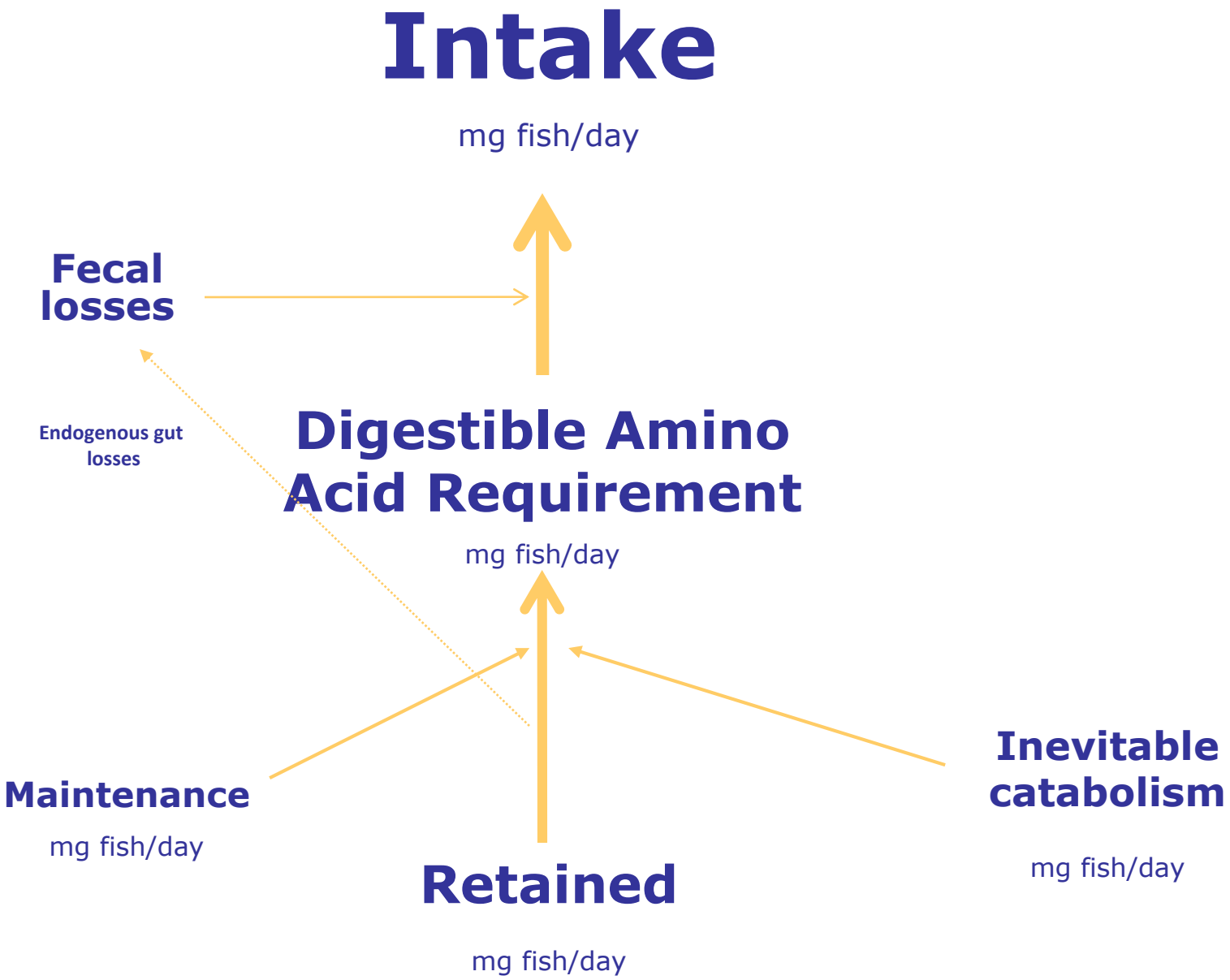


Inevitable catabolism = 1 – Efficiency Slope

Maintenance = intercept

Retained methionine (g/fish) vs. methionine intake (g/fish)

Factorial Amino Acid Requirement Model



Factorial Model of Amino Acid Requirement Model

Absolute EAA (e.g. Met) Requirement
(g per fish per day)

Divided by

Expected feed intake
(g fish per day)

← How do you get this value?

Equal

Optimal Dietary Concentration
(%, mg/kg, kcal/kg)

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Bioenergetics-Based Factorial Model to Determine Feed Requirement and Waste Output of Tilapia Produced under Commercial Conditions

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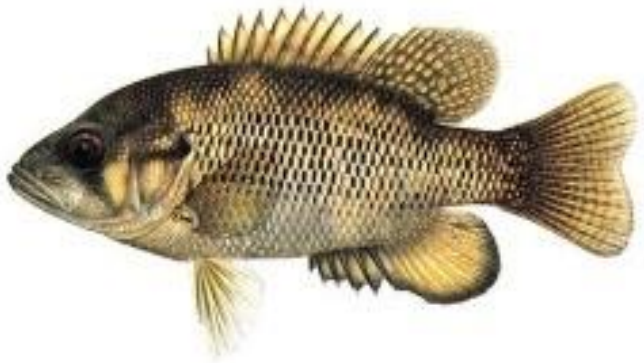
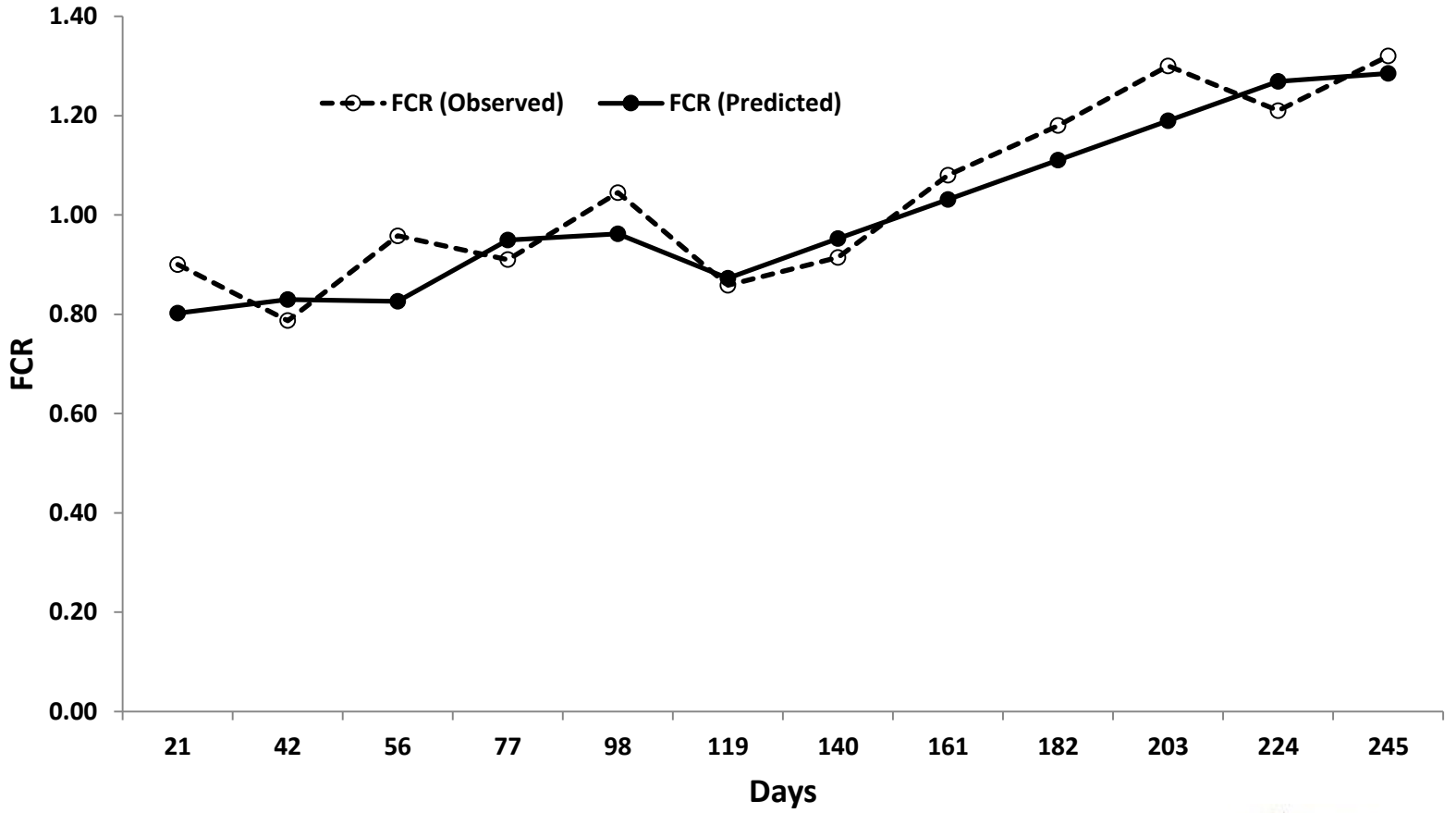
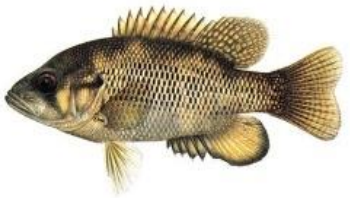
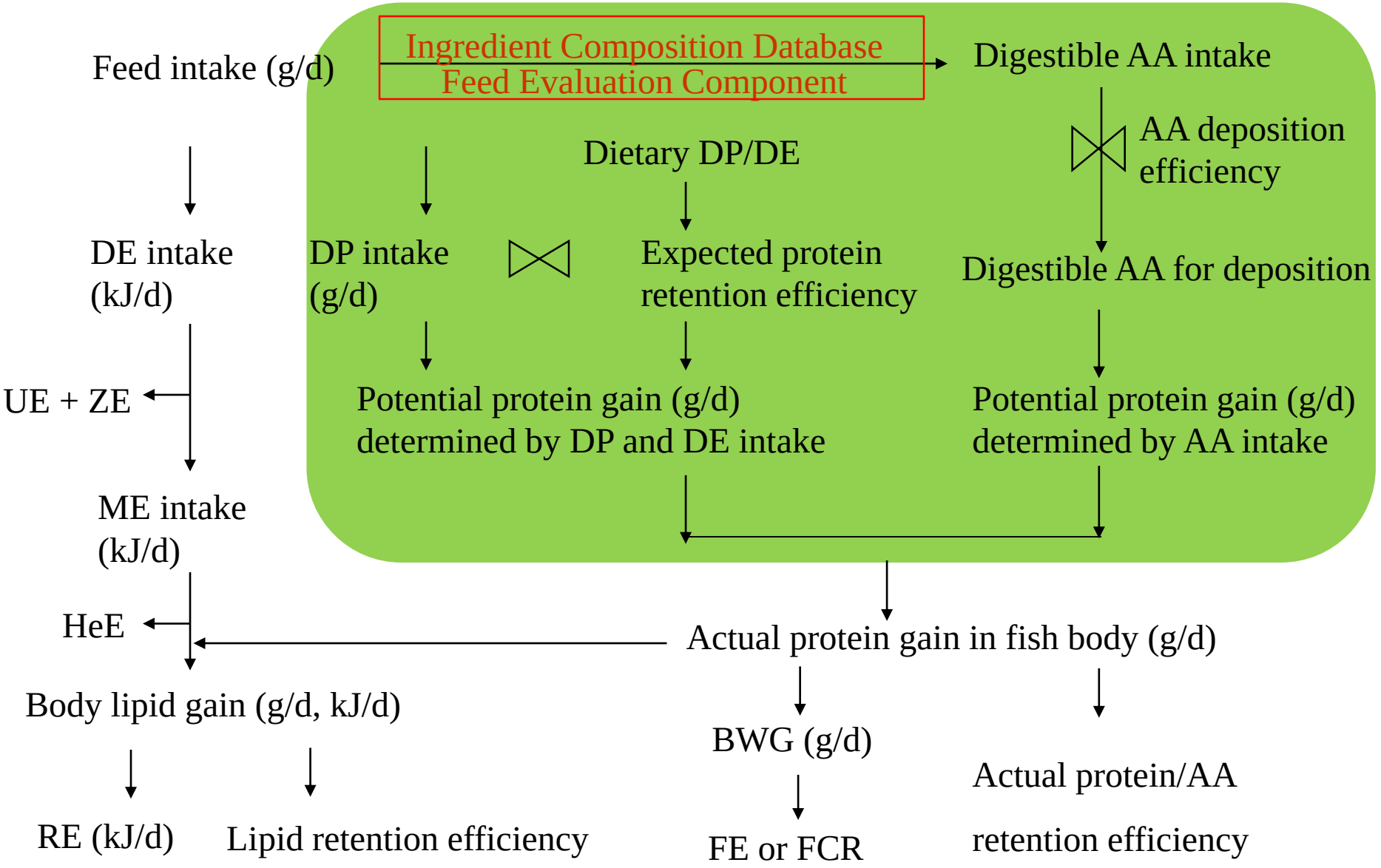


Observed and predicted evolution of feed conversion ratio (feed:gain) of Nile tilapia during a pilot-scale trial



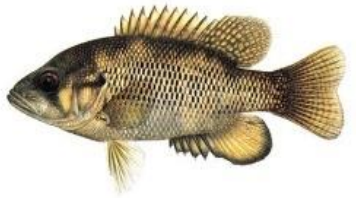


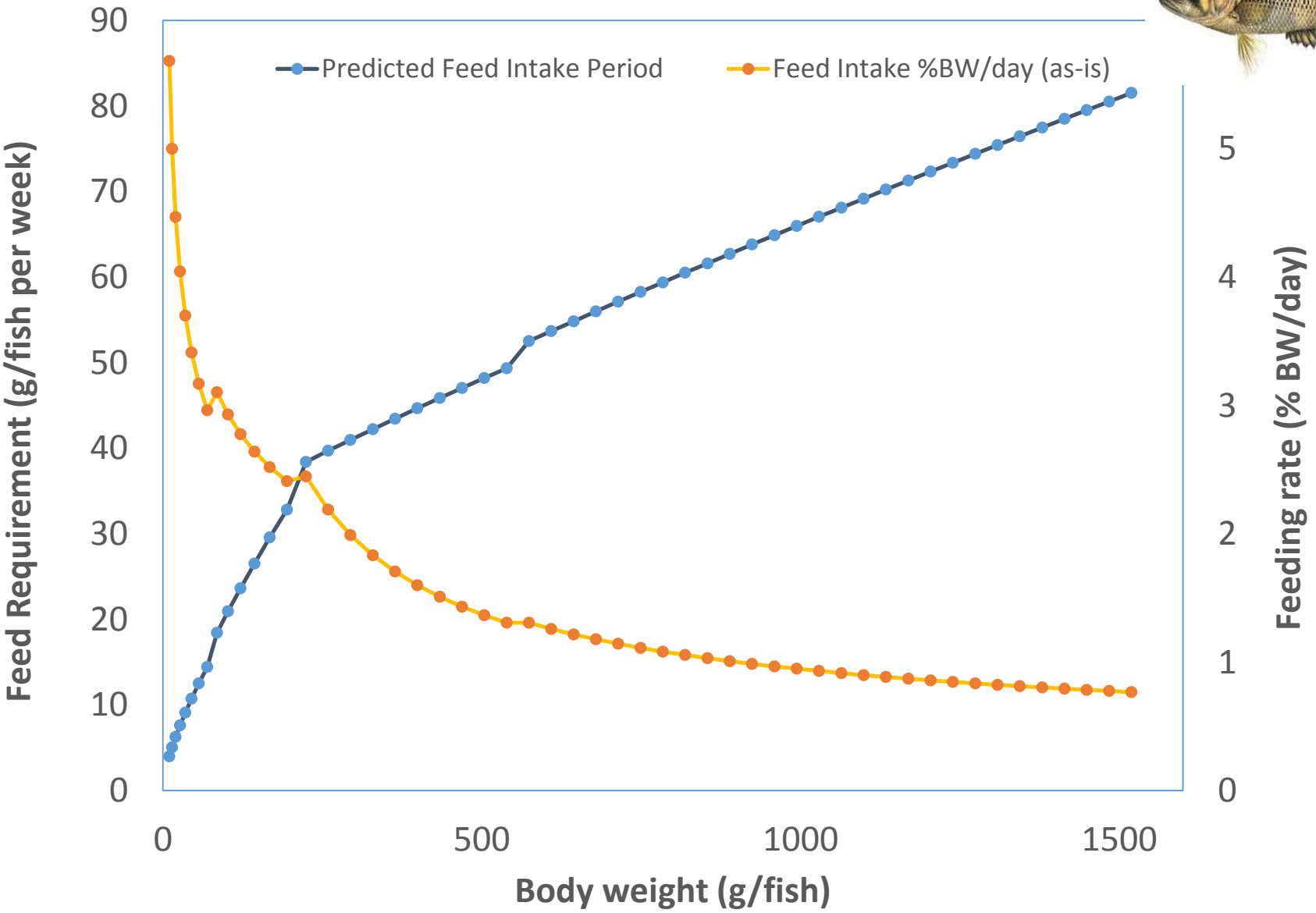
A Factorial Essential Amino Acid - Bioenergetic Hybrid Model



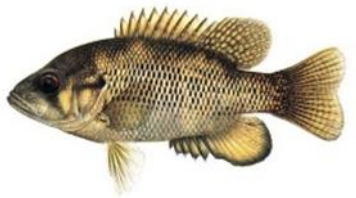
Hua and Bureau (2012)

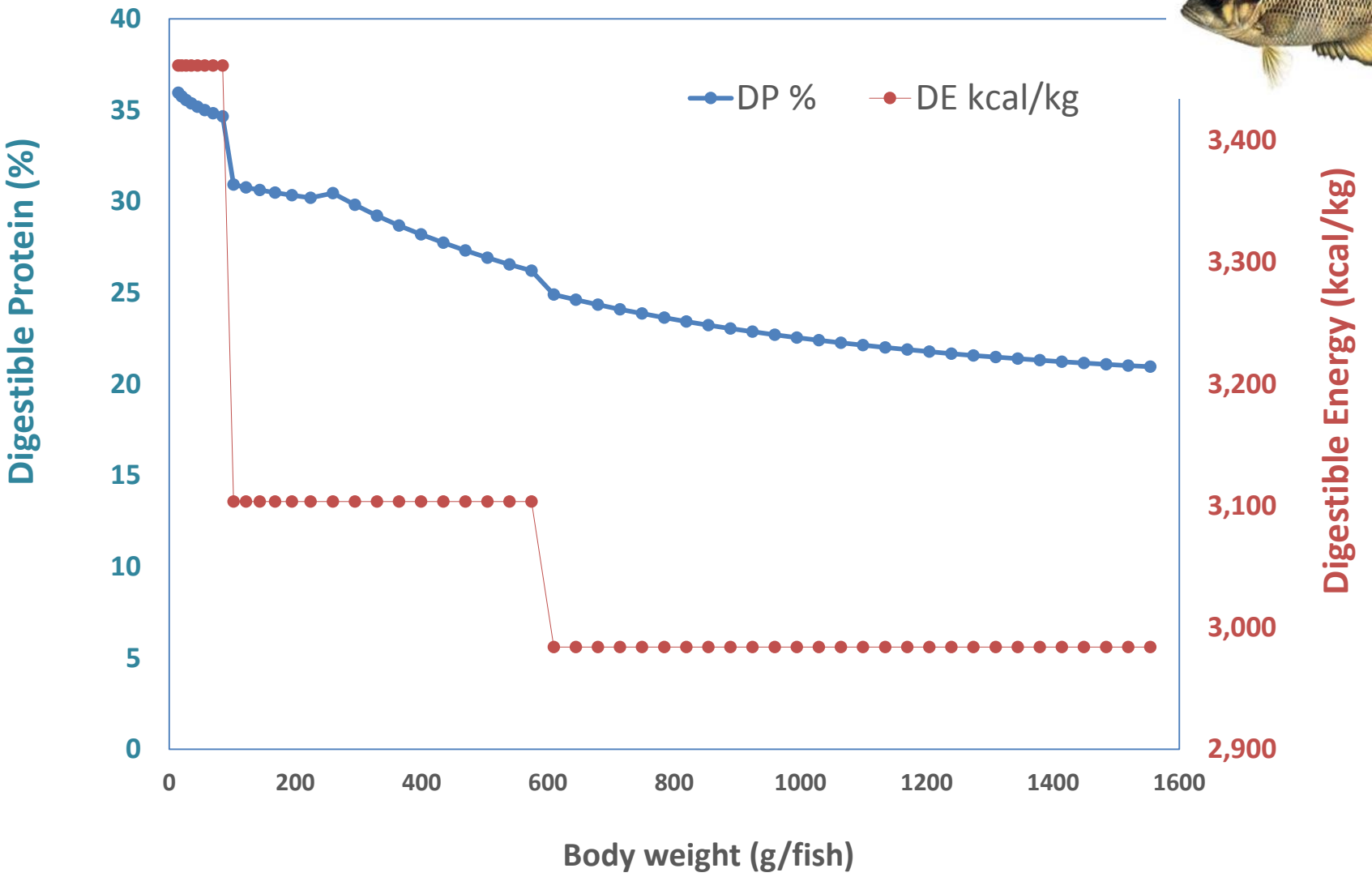
Simulated feed intake of Nile tilapia of increasing weight



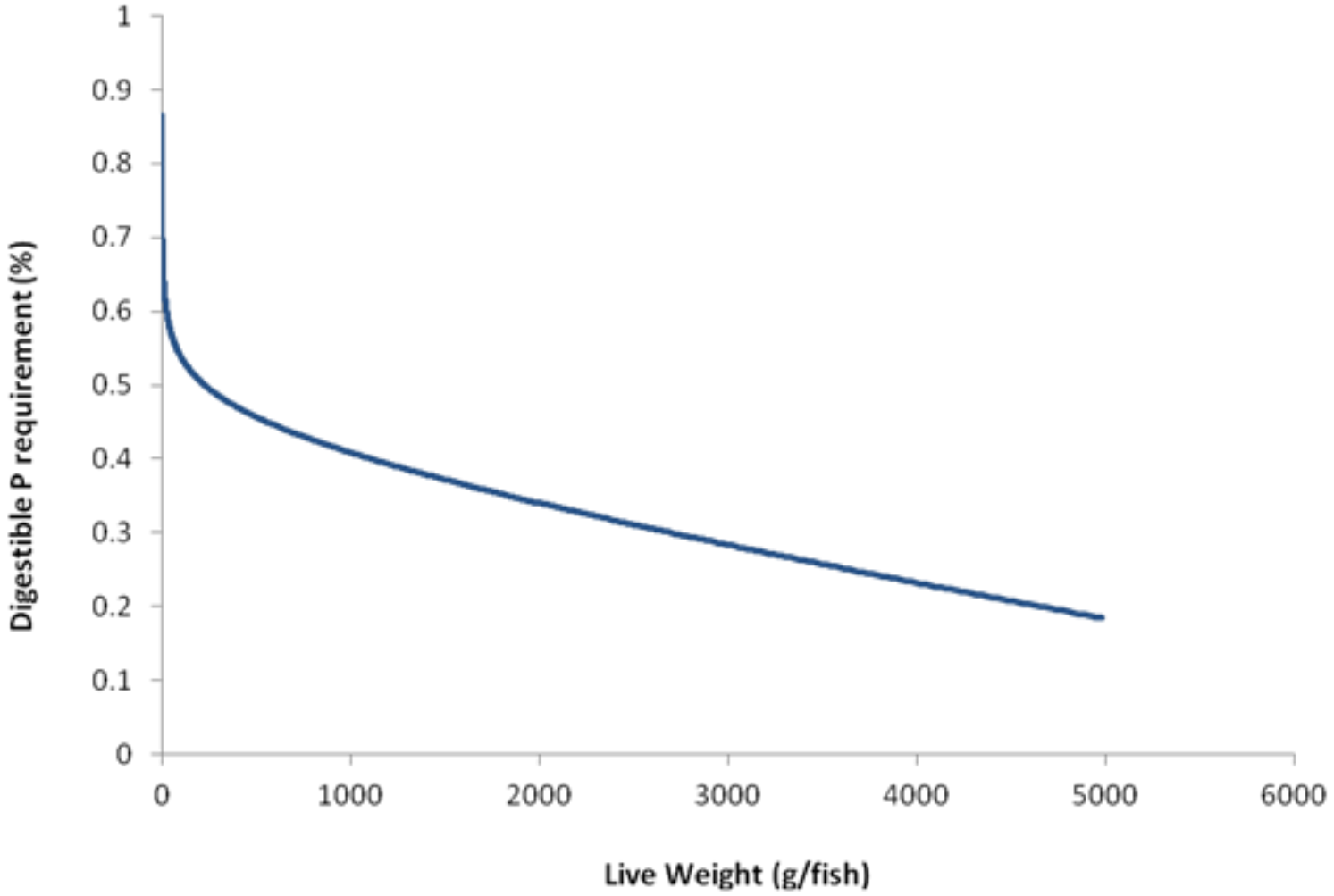


Predicted Optimal Digestible Protein and Digestible Energy Content of Nile Tilapia Feeds





Theoretical estimate of digestible P requirement of Atlantic salmon of increasing weights



Theoretical estimate of digestible P requirement of Atlantic salmon of increasing weights.

	Weight Class g/fish				
	0.2 – 20	20 - 500	500 - 1500	1500 - 3000	3000 - 5000
Expected FCR, feed:gain*	0.7	0.8	1.0	1.2	1.6
Dig. P Requirement, Mean, %	0.74	0.55	0.44	0.35	0.25
Dig. P Requirement, Range, % **	0.91-0.64	0.64-0.48	0.48-0.39	0.39-0.30	0.30-0.20

Estimates derived from a factorial modeling exercise (Feed with 20 MJ DE) based on the model described by Hua and Bureau (2012) and used in modeling exercises developed for the NRC (2011).

P Content of Common Fish Feed Ingredients

Ingredients	P content (%)
Fish meal	1.08 – 4.19
Meat and bone meal	2.49 – 7.08
Poultry by-product meal	1.65 – 3.45
Blood meal	0.08 – 1.71
Feather meal	0.54 – 1.26
Corn gluten meal	0.44 – 0.55
Soybean meal	0.64 – 0.85
Wheat middling	0.97 – 1.17

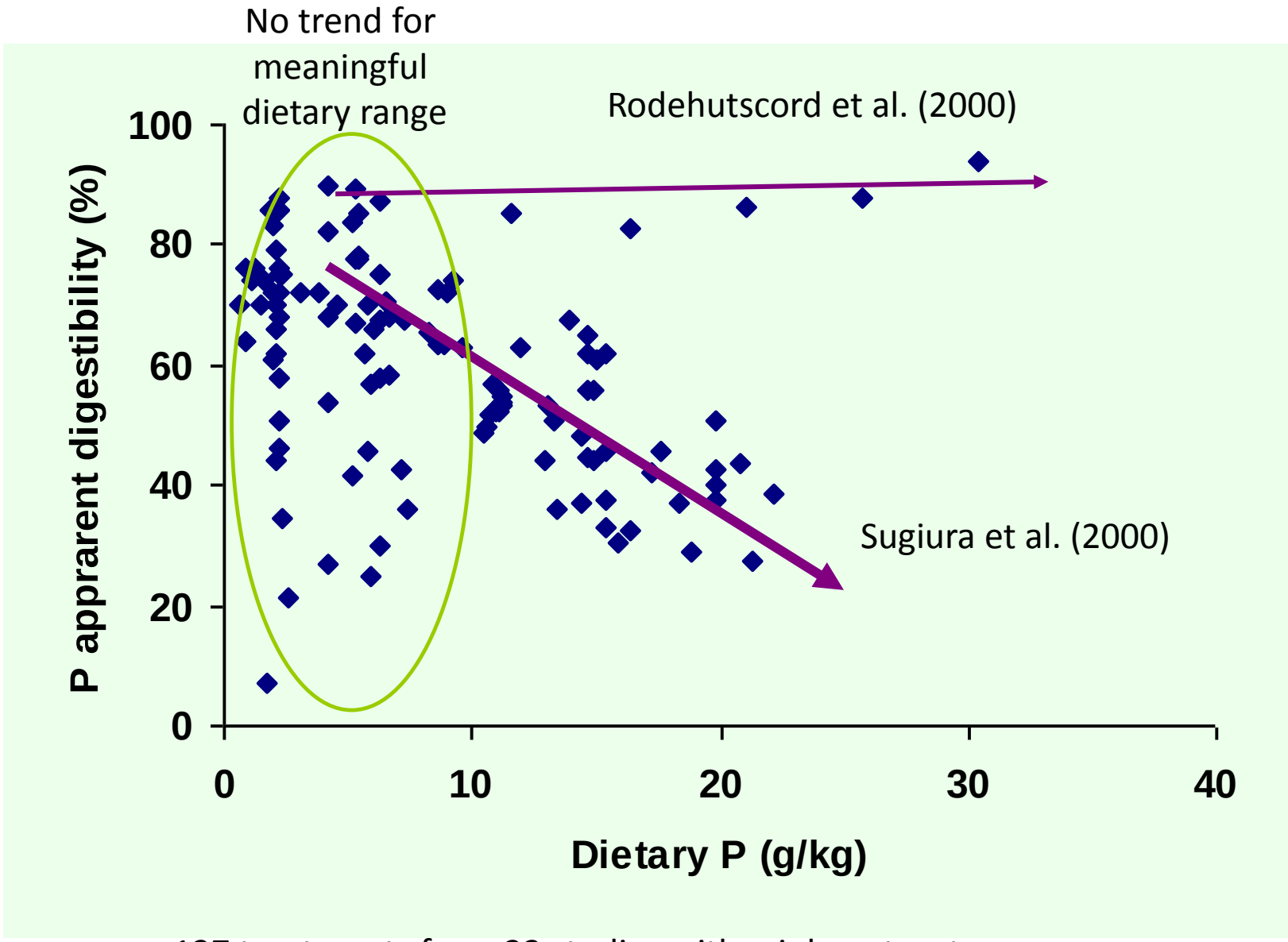
Summarized from various sources in literature

Estimates of Apparent Digestibility Coefficient (ADC) of P in Salmonids feed Ingredients

Ingredient	ADC (%)
Fish meal	17 - 81
Meat and bone meal	22 - 67
Poultry by-products meal	38 - 66
Feather meal	68 - 82
Blood meal	70 - 104
Soybean meal	27 - 46
Corn gluten meal	<10
NaH_2PO_4	95 - 98
$Ca(H_2PO_4)_2$	90 - 94
$CaHPO_4$	54 - 77
$Ca_{10}(OH)_2(PO4)_6$ or $Ca_3(PO_4)_2$	37 - 64

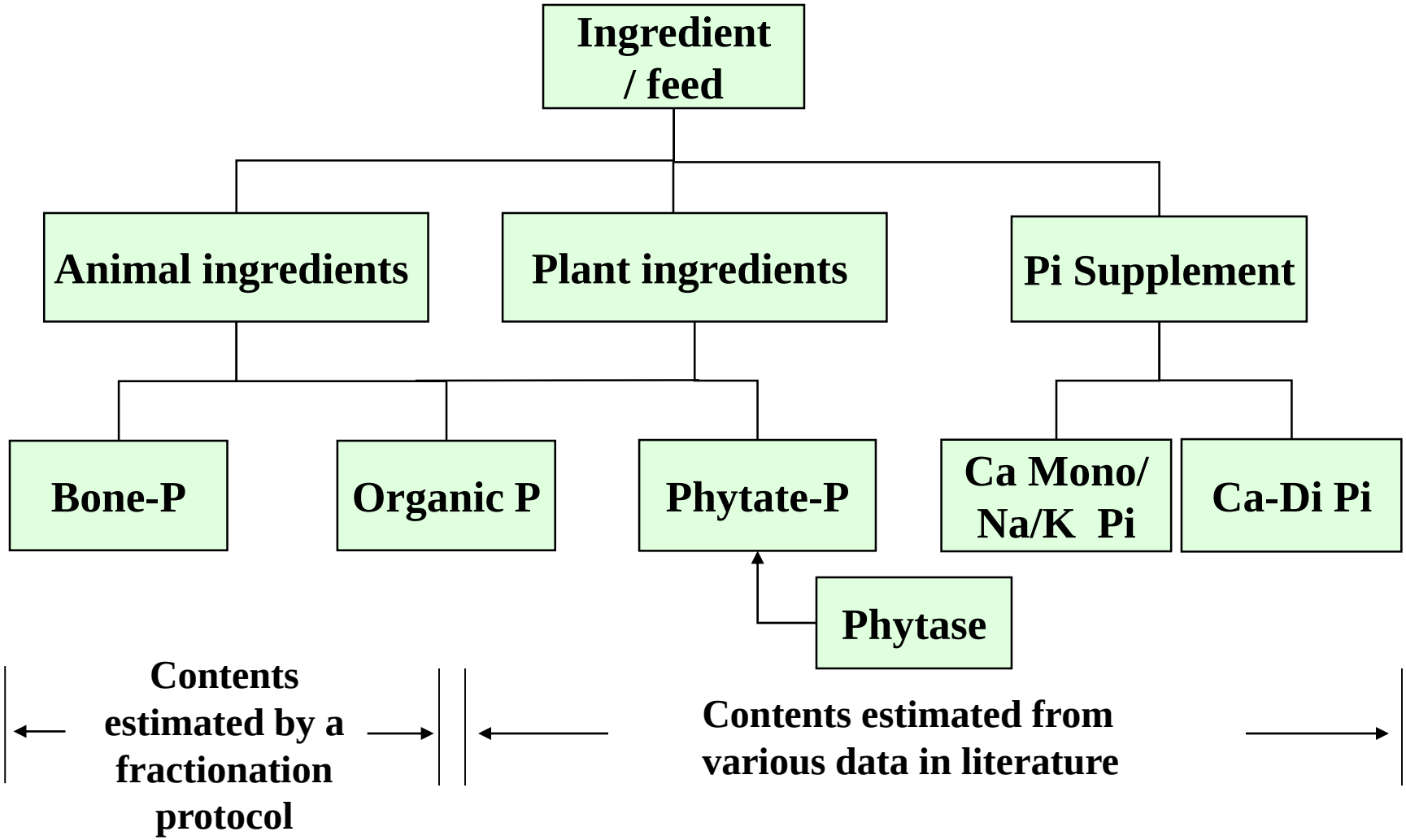
Summarized from various sources in literature

Dietary Phosphorus Digestibility

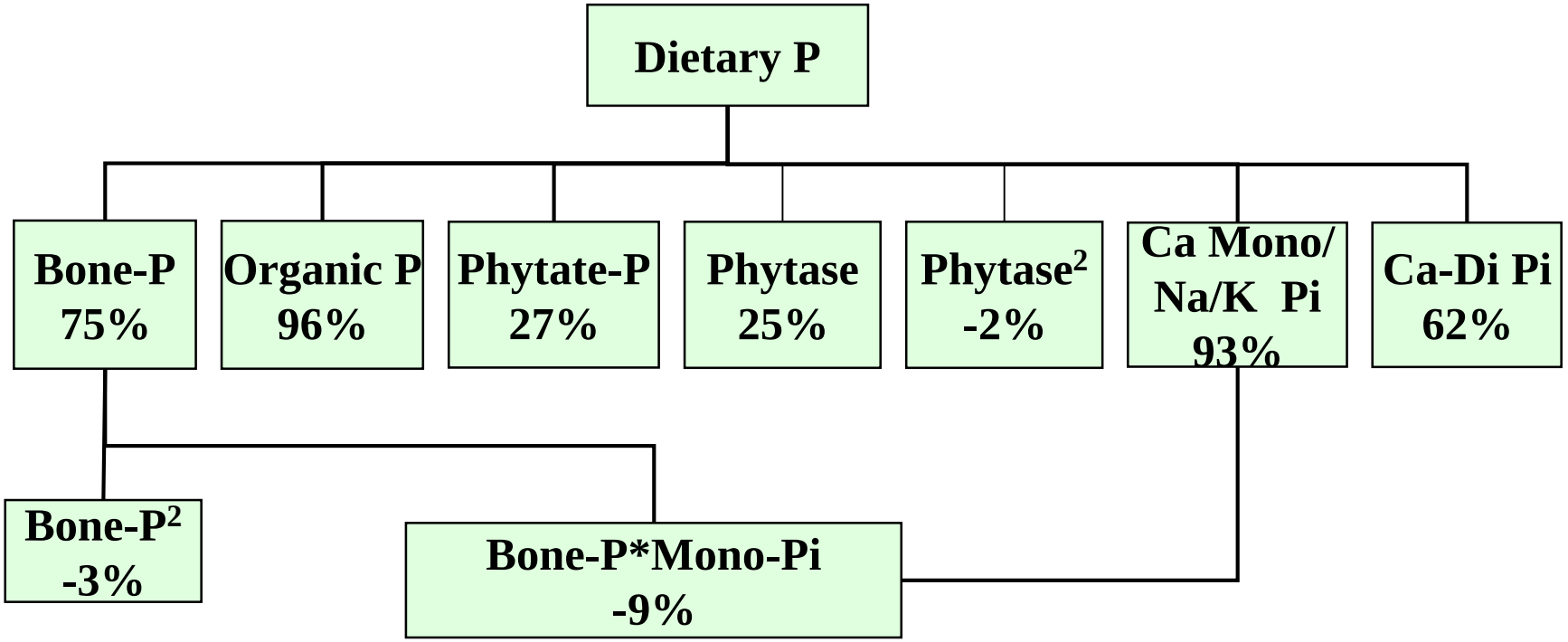


137 treatments from 22 studies with rainbow trout

Classification and Content of P Compounds



P Digestibility Model for Tilapia



$$\begin{aligned}\text{Digestible P} = {} & 0.75\ \text{bone–P} \\ & + 0.27\ \text{phytate–P} \\ & + 0.95\ \text{organic P} \\ & + 0.93\ \text{Ca monobasic /Na/ K Pi supplement} \\ & + 0.62\ \text{Ca dibasic Pi supplement} \\ & + 0.25\ \text{phytase/phytate} \\ & - 0.02\ (\text{phytase/phytate})^2 \\ & - 0.03\ (\text{bone–P})^2 \\ & - 0.09\ \text{bone–P} \\ & \times\ \text{*Ca monobasic /Na/ K Pi supplement}\end{aligned}$$

Adequately and Cost-Effectively Meeting Requirements

Key Strategies:

1- Determining nutrient requirements across life stages

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

2- Cost-effectively meeting nutrient requirements

Effective approach:
- Fine chemical characterization of ingredients
- Digestibility trials, *in vitro* lab analysis
- Use nutritional models (digestible nutrients)
- Use additives and processing techniques

3- Verifying if predictions correspond to commercial reality

Effective approach:
- Benchmarking / production modeling
- Investment in Research & Development (R&D)
- Never be satisfied with status quo

Summary – Take Home Message

1) Natural tendency towards focusing on ingredient and proximate composition of feeds

2) Animals have a need for nutrients, not for ingredients, proximate components, and even for “energy”

3) Formulation on ingredient basis sometimes needed to palliate to our lack of understanding (poorly characterized nutrients)

4) Formulating aquafeeds is a complex endeavor, with many nutrients, differences between species, life stages, different feed grades, etc. Important role for nutritional modeling approaches

5) Adequate characterization of the ingredients = 50% of the success.

6) “The proof of the pudding is in the eating” – Testing is essential