The Challenge of Defining and Meeting the Essential Amino Acid Requirements of Fish:

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BACKGROUND

- Fish meal is increasingly being replaced by more economical protein sources with different amino acid profiles.
- Increase reliance on ingredients with poorer amino acid profiles, brings the need to pay greater attention to the EAA requirements of fish.
- Composition of aquaculture feeds has evolved rapidly and these feeds can be formulated to widely different protein, lipids and digestible energy levels.

    Salmonid feed composition can vary from: 33-60 % CP and 12–40% lipid.

- Growth rates and feed efficiencies achieved today are much better in those in the past.
- This impose a significant challenge to our ability to interpret information on nutrient requirements in fish in the literature and then make practical recommendations.

Complementarity of Corn Gluten Meal and Soybean Meal as Protein Sources in the Diet of Young Atlantic Salmon

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CANADA

Presented at the IX International Symposium on Nutrition and Feeding in Fish, Miyazaki, Japan, 2000.

Materials and Methods

Fish:

Atlantic salmon (*Salmo salar* L.)
Anadromous, LaHave River strain (wild)
initial body weight = 5.3 g/fish

Experimental Design and Conditions:

Six diets, 3 replicates
Water temperature = 15°C
Duration = 24 weeks

Diets:

40% digestible protein (DP)
20 MJ/kg digestible energy (DE)
20 g/MJ DP/DE
Nutrients in excess of NRC (1993) requirements

Diet Formulation

Ingredients	Diets					
	1	2	3	4	5	6
Fish meal, herring, 68% CP	20	20	20	20	56	38
Corn gluten meal, 60% CP	10	20	30	40	-	20
Soybean meal, 48% CP	35	23	12	-	-	-
Blood meal, spray-dried	5	5	5	5	5	5
Whey	8.3	9	9	9	10	10
Starch, raw	-	1.4	2.4	4.5	10	7
$CaHPO_4$	0.4	0.4	0.4	0.4	-	-
Vitamins and minerals	2	2	2	2	2	2
Fish oil, herring	19.3	19.2	19.2	19.1	17	18
Total	100	100	100	100	100	100

Performance of Atlantic salmon fed over 24 weeks

Parameters	Diets					
	1	2	3	4	5	6
Final body weight, g/fish	83 bc	88 a	87 a	81 c	86 ab	87 a
Feed efficiency, G:F	1.16b	1.24a	1.22a	1.16b	1.21a	1.24a
TGC	0.104bc	0.107a	0.107a	0.103c	0.106ab	0.107a
Nitrogen gain, g/fish	2.2	2.3	2.2	2.2	2.3	2.3
Energy gain, kJ/fish	689	731	751	693	698	706

Initial body weight = 5.3 g/fish

Thermal-unit growth coefficient (TGC) = $(FBW^{1/3} - IBW^{1/3})/(Day*°C)$

BACKGROUND

- The mode of expression of amino acid requirements of fish is a topic of disagreement between fish nutritionists.

  I. Kim *et al*., 1991; NRC, 1993: consider that EAA requirements are best expressed as a percentage of diet **(% diet)**.

  II. Rodehutscord *et al*., 1997; EAA requirements should be expressed in relation to the diet energy content (e.g. **g/MJ DE**).

  III. Cowey and Cho, 1993: EAA requirements are best expressed in relation to the dietary protein content (**% protein** or **g/16 g N**).

- Individual EAA levels deemed adequate in the diet may be different depending on: mode of expression adopted, composition of diet and amino acids profile of the ingredients.

Different Modes of Expression =
Dramatically Different and Largely Contradictory Assumptions

- **% of diet: Assumes that the diet composition has no effect on amino acid requirement (relative to the "mass" of diet).**

- **g/MJ digestible energy (DE): Assumes that the amino acid requirement is directly to DE intake. Higher DE will need to be higher in EAA compared to lower DE feeds (since lower feed intake with high DE feeds).**

- **% of protein: Assumes when excess amino acid are catabolized for energy, first limiting amino acid is not spared compare to other, less limiting, amino acids. Assumes that if formulate to amino acid levels in excess of requirement, excess protein must be "balanced" (respect certain proportion for each amino acids) .**

One can make a case *for* and *against* each of these modes of expression

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Arginine requirement of rainbow trout fish according to three different modes of expression.

References	Requirement
NRC (1993)	1.5 % diet
Rodethutscord et al (1997)*	1.0 g/MJ digestible energy
Mambrini and Guillaume (1999)	4.4 % protein (g/ 16 g N)

NRC (1993) Essential Amino Acid Requirements Computed According to Different Schools of Thoughts

EAA Requirement	Lys	Met+ Cys	Arg	Thr	Trp	His	Val	Leu	Iso	Phe+ Tyr	Sum EAA
%diet	1.8	1.0	1.5	0.8	0.2	0.7	1.2	1.4	0.9	1.8	11.3
g/MJ DE	1.2	0.67	1.00	0.53	0.13	0.47	0.80	0.93	0.60	1.20	7.53
%protein	4.8	3.3	4.4	2.0	0.6	1.6	5.3	3.6	2.0	5.3	-

Encarnaçaõ and Bureau (2001)

TABLE 6

Recommended dietary amino acid concentrations

	Lysine	Methionine[1]	Arginine[2]	Threonine[2]	Tryptophan	Histidine	Valine	Leucine	Isoleucine
Own results[3]									
dry matter, *g/kg*	27.7	8.0	11.5	10.3	2.0	5.8	15.7	13.6	13.7
digestible energy, *g/MJ*	1.38	0.40	0.57	0.51	0.10	0.29	0.78	0.68	0.68
NRC (1993)									
digestible energy,[4] *g/MJ*	1.19	0.665[5]	0.99	0.53	0.13	0.46	0.80	0.93	0.60

[1] Results from Rodehutscord et al. (1995a).
[2] Results from Rodehutscord et al. (1995b).
[3] Concentrations required to reach 95% of plateau in protein deposition.
[4] Recalculated values.
[5] Methionine + Cystine.

Rodehutscord et al. (**1997**)

Digestible Lysine Content of Experimental Diets

	Diet			
Digestible Lysine	1	2	3	4
Calculated content, % DM	3.06	2.74	2.45	2.12
% above/under requirement:				
NRC (1993), % diet	70	52	36	18
NRC (1993), g/MJ DE	20	6	-6	-20
Guillaume et al. (1999), g/16 g N	51	34	17	1

Performance of Atlantic salmon fed over 24 weeks

Parameters	Diets					
	1	2	3	4	5	6
Final body weight, g/fish	83 bc	88 a	87 a	81 c	86 ab	87 a
Feed efficiency, G:F	1.16b	1.24a	1.22a	1.16b	1.21a	1.24a
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Soybean meal, 48% CP	35	23	12	-	-	-
Blood meal, spray-dried	5	5	5	5	5	5
Whey	8.3	9	9	9	10	10
Starch, raw	-	1.4	2.4	4.5	10	7
$CaHPO_4$	0.4	0.4	0.4	0.4	-	-
Vitamins and minerals	2	2	2	2	2	2
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Total	100	100	100	100	100	100

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Digestible Lysine Content of Experimental Diets

	Diet			
Digestible Lysine	**1**	**2**	**3**	**4**
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% above/under requirement:				
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NRC (1993), g/MJ DE	**20**	**6**	**-6**	**-20**
Guillaume et al. (1999), g/16 g N	**51**	**34**	**17**	**1**

Solution : Compute EAA content of feeds using three modes of expression and use highest value?!

Mode of Expression Adopted will Result in Different Formulation Targets!

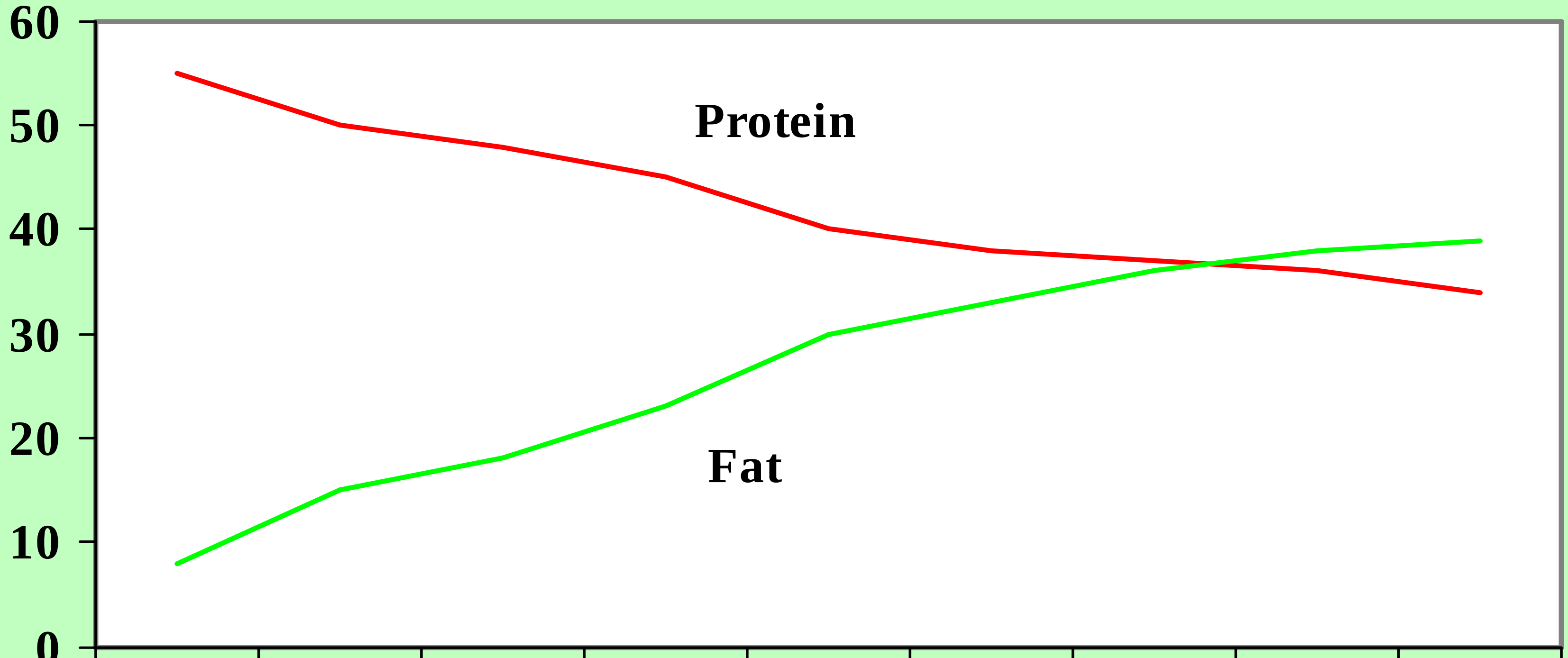
Composition	Starter	Grower	High energy
Crude Protein, %	51	44	38
Lipids, %	16	28	33
Digestible energy, MJ/kg	17	20	22

School of thought**	Lysine level deemed adequate (g/kg feed)		
1) % diet	18	18	18
2) g/MJ DE	22	24	26
3) % Protein	25	21	18
High-Low, % difference	36	33	47

Why are we spending so much effort on research?

How can we expect feed manufacturers to be able to least-cost feeds?

Protein/fat development in salmon feed 1972 - 2004



	1972	1975	1980	1985	1989	1992	1996	1998	2004
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

Central Questions

How reliable are estimates of amino acid requirements found in the reference literature (e.g. NRC, 1993)?

What the best mode of expression of essential amino acid requirements?

How does composition of the diet affect essential amino acid utilization and requirements?

How does fish species, life stage, growth rate, feed efficiency, etc. affect utilization and requirement of essential amino acids?

Meeting NRC (1993) Lysine Requirement (1.8% diet)

Ingredients	Diet 1	Diet 2	Diet 3	NRC
Fish meal	40	18	18	
Corn gluten meal	11	49	49	
Fish oil	14	14	14	
L-Lysine	-	-	0.5	
Composition				
Digestible protein, %	43	43	43	
Digestible energy, MJ/kg	19	19	19	
Digestible Lysine				
% diet	3.2	1.8	2.3	1.8
% protein	7.4	4.0	5.2	4.8

Performance of Rainbow Trout Fed Diets Meeting NRC (1993) Lysine Requirement (1.8% Diet) vs. Diet with >2.2% Lysine

	Diet			
Digestible Lysine	1	2	3	NRC
% diet	3.2	1.8	2.3	1.8
% protein	7.4	4.0	5.2	4.8
Part 1 (Week 1-12)				
Growth rate, TGC	0.26a	0.21b		
Feed eff., gain:feed	1.19a	0.94b		
Part 2 (Week 13-16)				
Growth rate, TGC	0.26a		0.28a	
Feed eff., gain:feed	1.07a		1.11a	

*TGC = 100 ($FBW^{1/3}$ - $IBW^{1/3}$) / (Temp. (^{o}C) * days)

Lysine Requirement of Rainbow Trout – Summary of Published Studies

Reference	CP	Lipid	No. of Levels	Lysine Conc.	TGC	Response variable	Model	Est. Lysine Requirement
	%	%	n	%	%			
Ketola (1983)	47	12	5	0.5-2.9	0.12	Weight gain	ANOVA	2.9% diet
Walton et al.(1984)	45	17	7	1.0-2.6	0.17	Weight gain	Broken Line	1.9% diet
Lanari et al.(1991)	40	n/a	n/a	n/a	n/a	Weight gain	Broken Line	2.2% diet
Kim et al.(1992)	35	10	8	0.7-1.6	0.20	Weight gain	Broken Line	1.3% diet
Pfeffer et al.(1992)	47	15	8	1.5-3.0	0.13	Protein gain	Polynomial	1.8% diet
Rodehutscord et al. (1997)	32	28	21	0.5-5.8	0.23	Weight gain	Exponential	2.3% diet
Encarnação et al.(2004)	40	24	6	1.2-2.4	0.22	Weight gain	Exponential	2.3% diet

NRC (1993) “established” lysine requirement at 1.8% diet

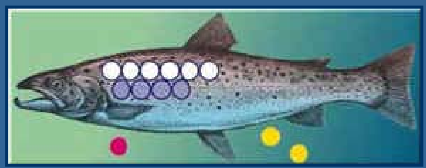
Source: Encarnação (2005)

Effect of Diet Composition on Lysine Utilisation and Requirement in Rainbow Trout (*Oncorhynchus mykiss*)

PhD Thesis

Pedro Encarnação

Fish Nutrition Research Laboratory
Department of Animal and Poultry Science
University of Guelph



OBJECTIVES

- Generate information required to improve our understanding of the factors affecting EAA utilization and requirements of fish.

- Examining the effects of diet composition (DE and different energy-yielding nutrients) on lysine utilisation and requirements of rainbow trout.

Study 1

Effect of dietary DE level on lysine requirements and utilization by rainbow trout

OBJECTIVES

To assess the effect of DE level/intake in the diet on lysine requirements :

- How does DE intake or dietary level affect the lysine intake and dietary requirement ?
- How DE level affects lysine utilization?

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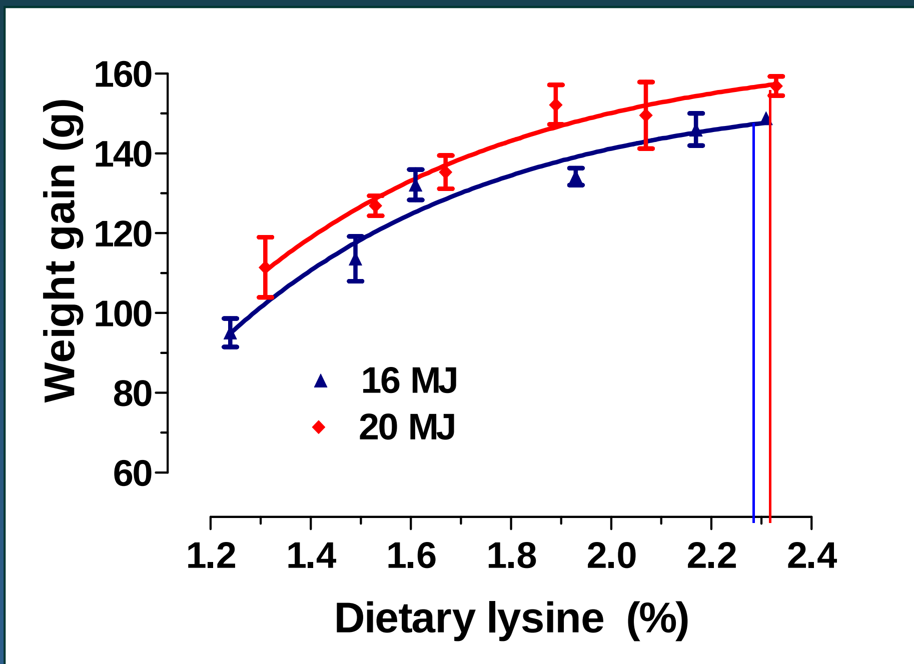
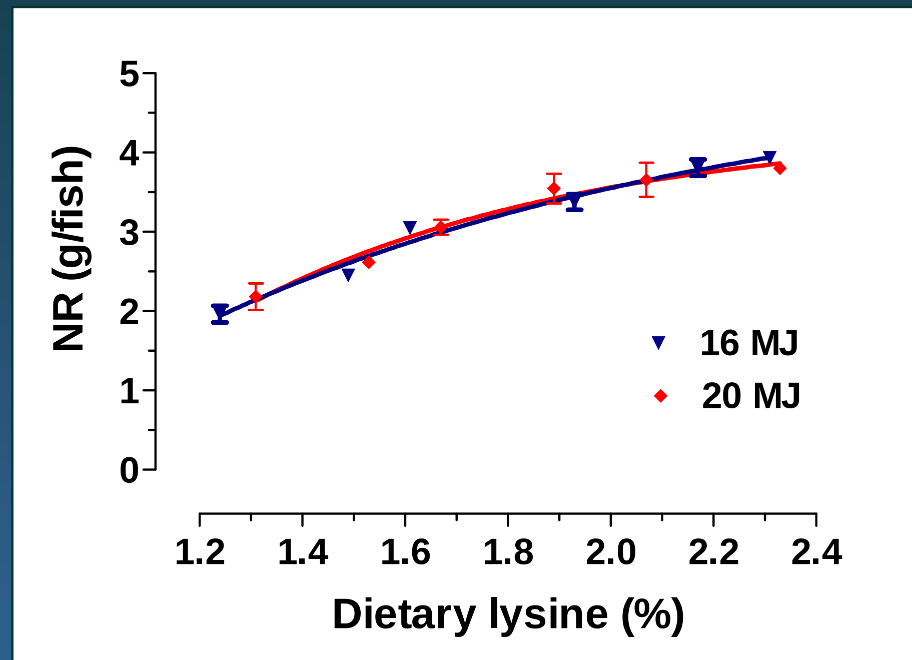
RESULTS

Figure 1 - Live weight gain in response to lysine intake at two DE levels.



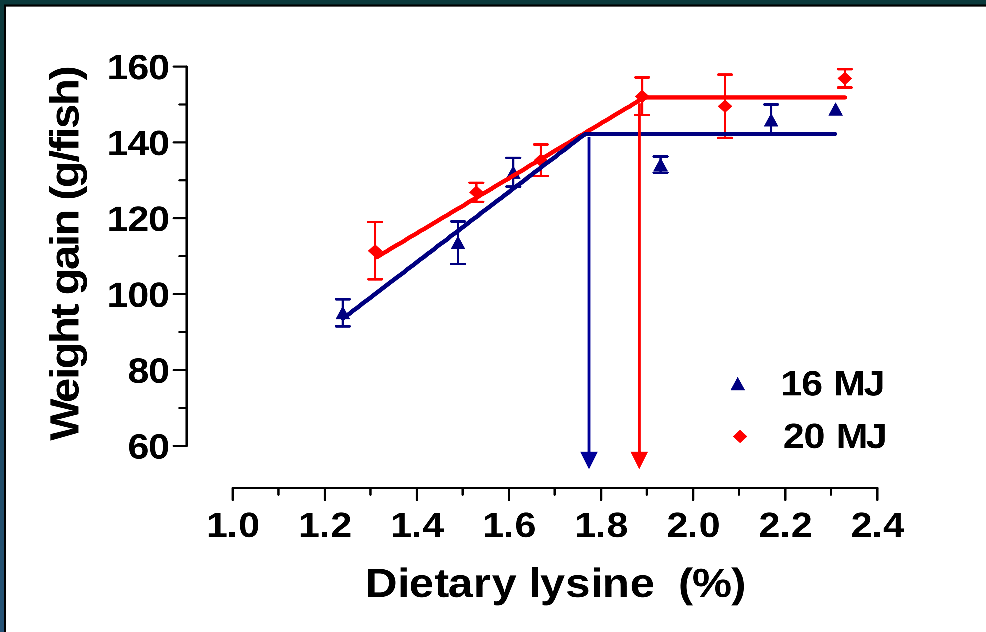
- ✓ Significant linear and quadratic effects to lysine and DE levels, no effect of DE level on lysine requirements (2.28 vs 2.33 %)

Figure 2 – N retention in response to dietary lysine concentration at two DE levels.



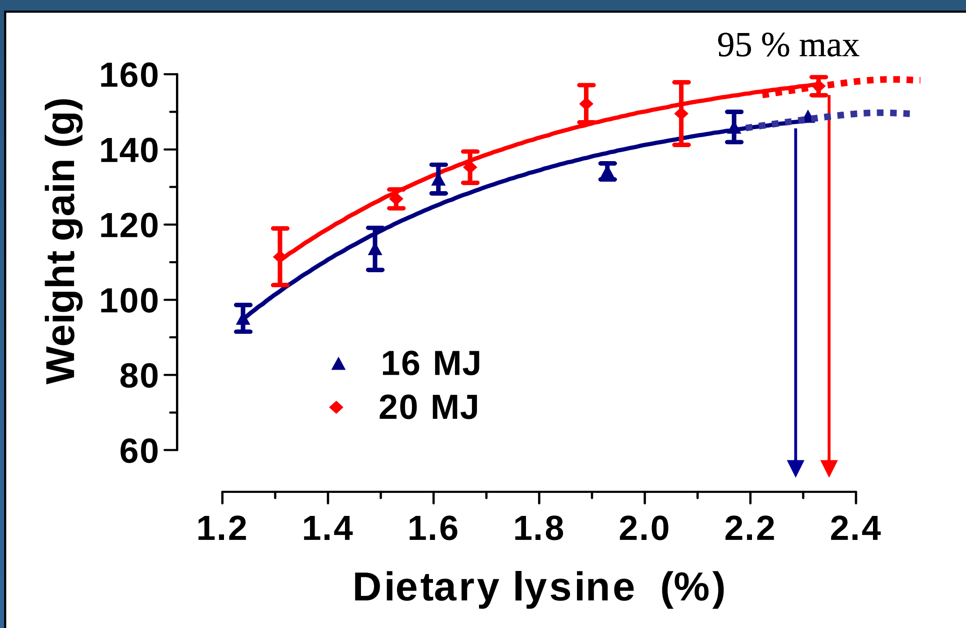
- ✓ No effect of dietary DE level on nitrogen retention.

Model Adopted Can Significantly Affect Estimate of Requirement



Broken line model

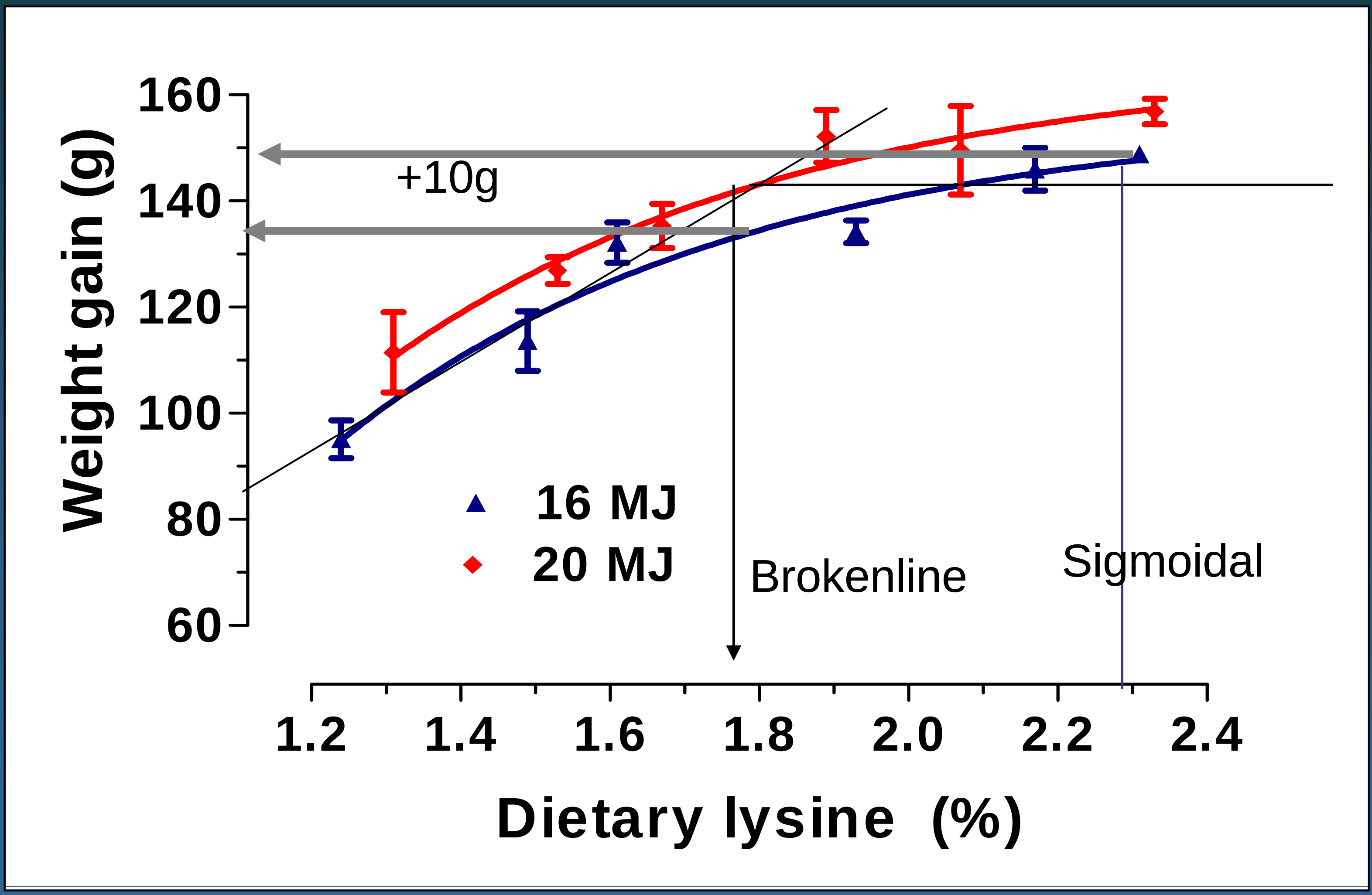
= 1.8% diet



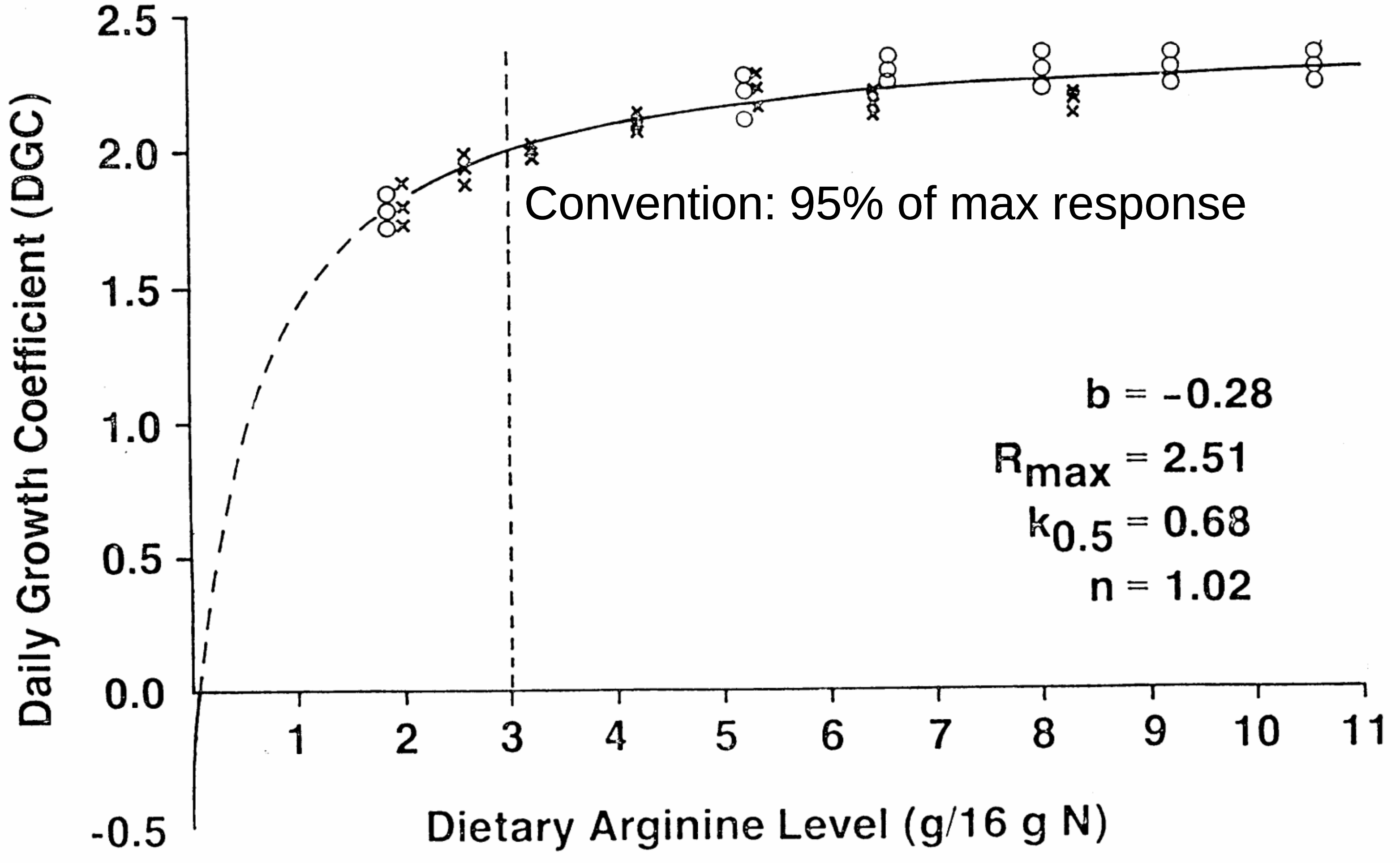
Nutritional kinetic model

= 2.3% diet

Model Adopted Can Very Significantly Affect Estimate of Requirement



Response of Rainbow trout to Increasing Arginine Levels



Cho, Kaushik and Woodward (1992)

Expressing Lysine Requirement as % of the Protein Content of the Diet is not Entirely Appropriate

Encarnacao et al. (2004):

Estimate of requirement :2.3% of diet DM
Diet: 40% crude protein

Estimated requirement = 5.75 g/ 100 g Protein

Rodehutscord (1997)

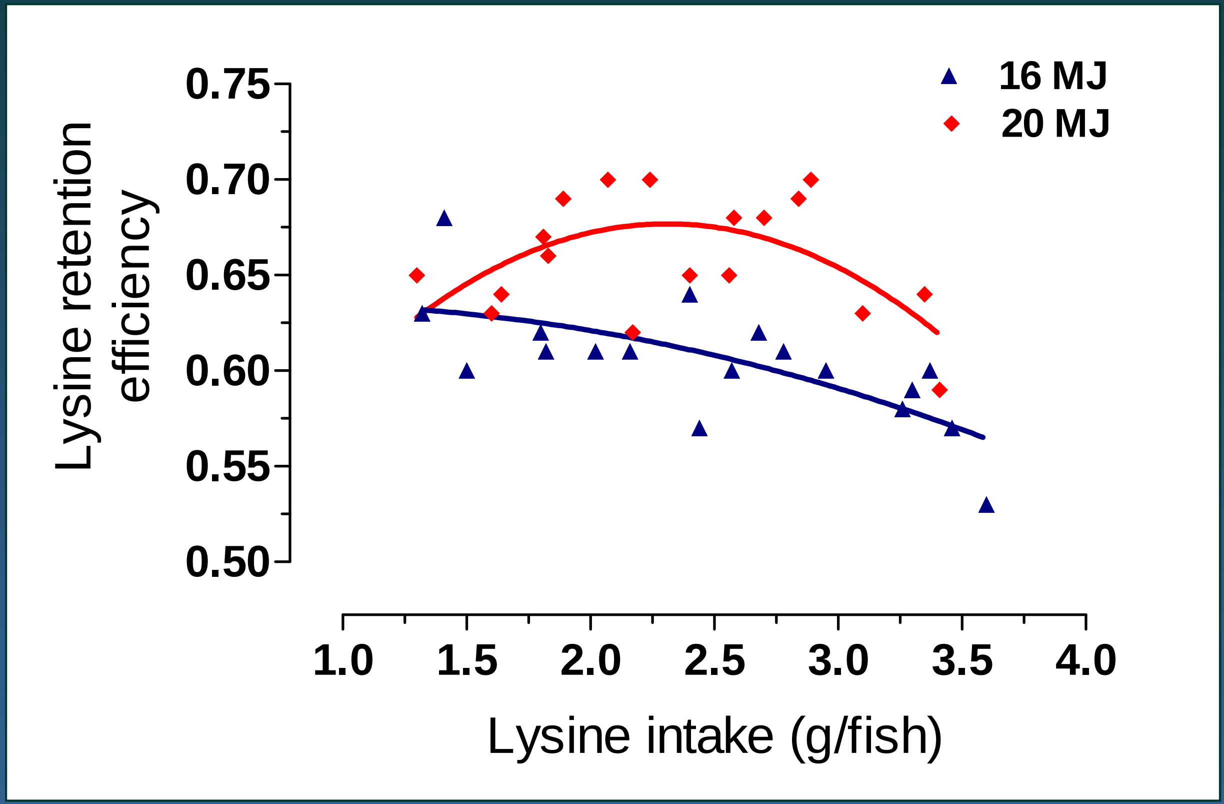
Estimate of requirement :2.3% of diet DM
Diet: 32% crude protein

Estimated requirement = 7.25 g/ 100 g Protein

Increasing number of other studies suggest that expressing amino acid requirement as % of the protein of the diet is not entirely appropriate, unless formulating to very low protein level where all amino acids are equally limiting.

RESULTS

Fig. 3 – Lysine efficiency in response to the lysine intake of fish.



✓ Higher efficiency of lysine utilization at higher dietary DE levels.

CONCLUSIONS

- Expressing EAA requirements in relation to DE content of the diet is not appropriate.

- Diet digestible energy (DE) content affects marginal efficiency of lysine utilization for protein deposition.

- When lysine was limiting, additional energy supplied by fish oil allowed lysine to be spared for protein deposition.

- Regulation of EAA utilization in fish could be different from other monogastric animals, at least pigs.

Mode of Expression Adopted will Result in Different Formulation Targets!

Composition	Starter	Grower	High energy
Crude Protein, %	51	44	38
Lipids, %	16	28	33
Digestible energy, MJ/kg	17	20	22
School of thought**	**Lysine level deemed adequate (g/kg feed)**		
1) % diet	18	18	18
2) g/MJ DE	22	24	26
3) % Protein	25	21	18
High-Low, % difference	36	33	47

Estimating Dietary Lysine Requirements for Live Weight Gain and Protein Deposition in Juvenile Rainbow Trout (Oncorhynchus mykiss)

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1 Nutrition Laboratory, Institute of Aquatic Economic Animals, School of Life Sciences, Sun Yat-Sen University, Guangzhou, P. R. China
2 Department of Animal and Poultry Science, University of Guelph, Ontario, Canada
3 Evonik-Degussa Corporation, Kennesaw, GA, 30144, USA

Presented at the XIV International Symposium on Nutrition and Feeding in Fish, Qingdao, China, 2010.

Introduction

Most of the estimates of essential amino acid (EAA) requirements have been determined based on live body weight gain as the response criteria.

Results from a number of studies have suggested that lysine requirement for maximum protein gain of rainbow trout is significantly higher than that for maximizing weight gain.

	Estimates of Lysine Requirement	
Reference	**Live weight gain**	**Protein gain**
	% diet DM	
Pfeffer et al. (1992)	1.8	2.2
Rodehutscord et al. (1997)	2.3	2.7
Encarnação et al. (2004)	2.3	~2.7

The experimental design (# of treatments, range of dietary lysine levels, # of replicates) of these studies was not sufficiently powerful to confidently determine if requirement for body protein gain is greater than that for live body weight gain.

There is insufficient information on effect of EAA on body composition as well as on efficiency of EAA utilization (useful information for nutritional models).

Objectives

1) To compare estimates of lysine requirement of rainbow trout using live weight gain and body protein deposition as the response criteria and different response fitting models.

2) To determine the efficiency of lysine utilization by rainbow trout

Materials and Methods

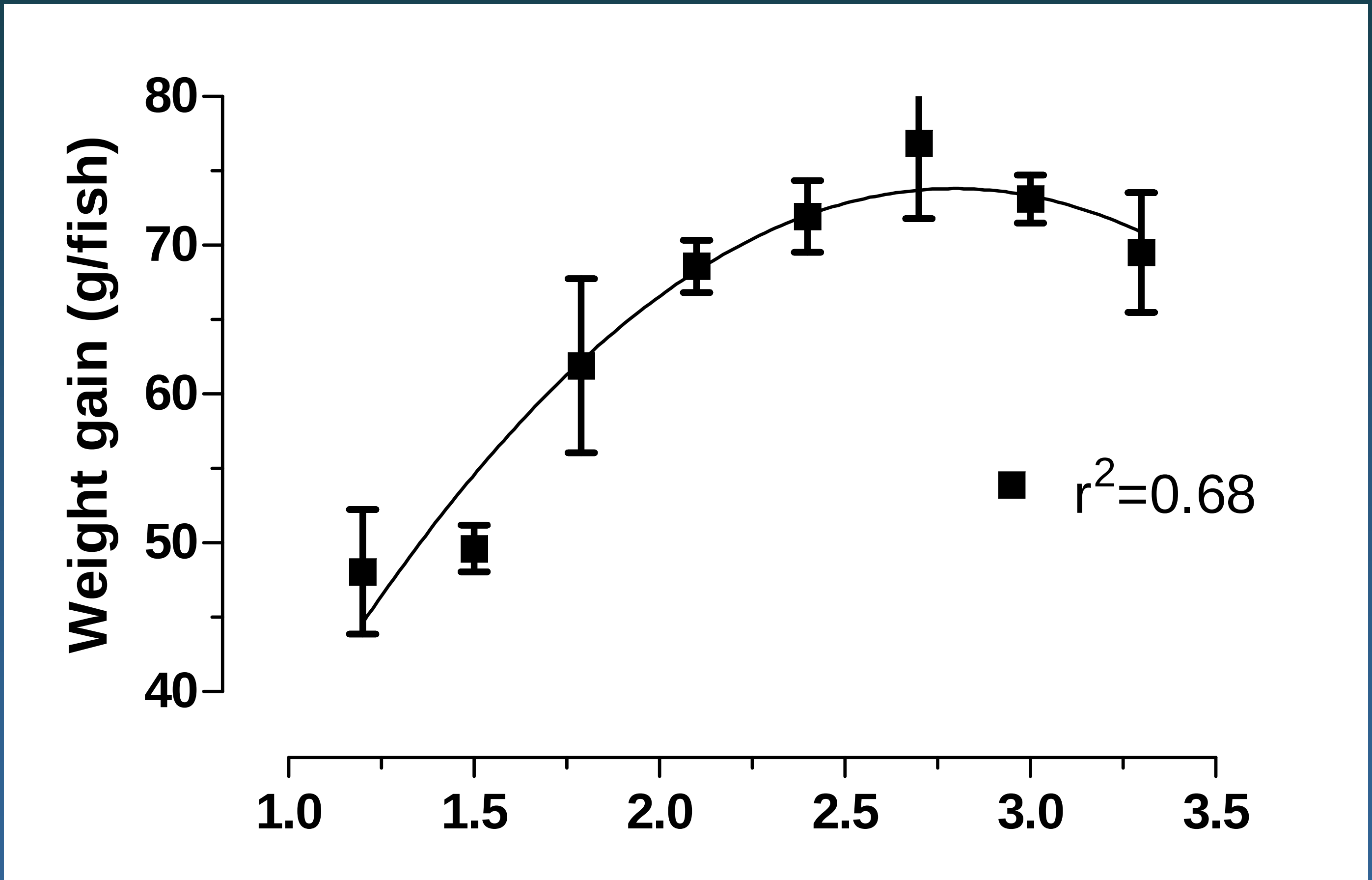
Fish: Rainbow trout (*Oncorhynchus mykiss*)
initial body weight = 5 g/fish

Design: 9 diets, 4 replicates
Complete Randomized Block Design
Water temperature =15°C
Duration= 12 weeks

Diets: >42% digestible protein (DP)
19 MJ/kg digestible energy (DE)
Nutrients >> in excess of NRC (1993) req.
EAA levels >110% of Rodehutscord (1997) except lysine

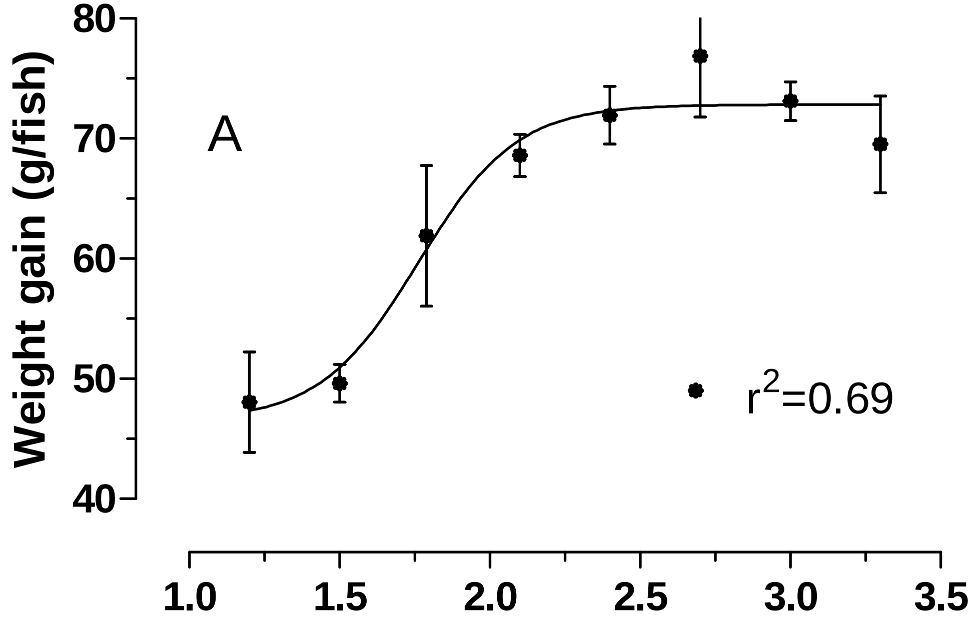
Results

Criteria: **Live weight gain** **Model:** **Quadratic**



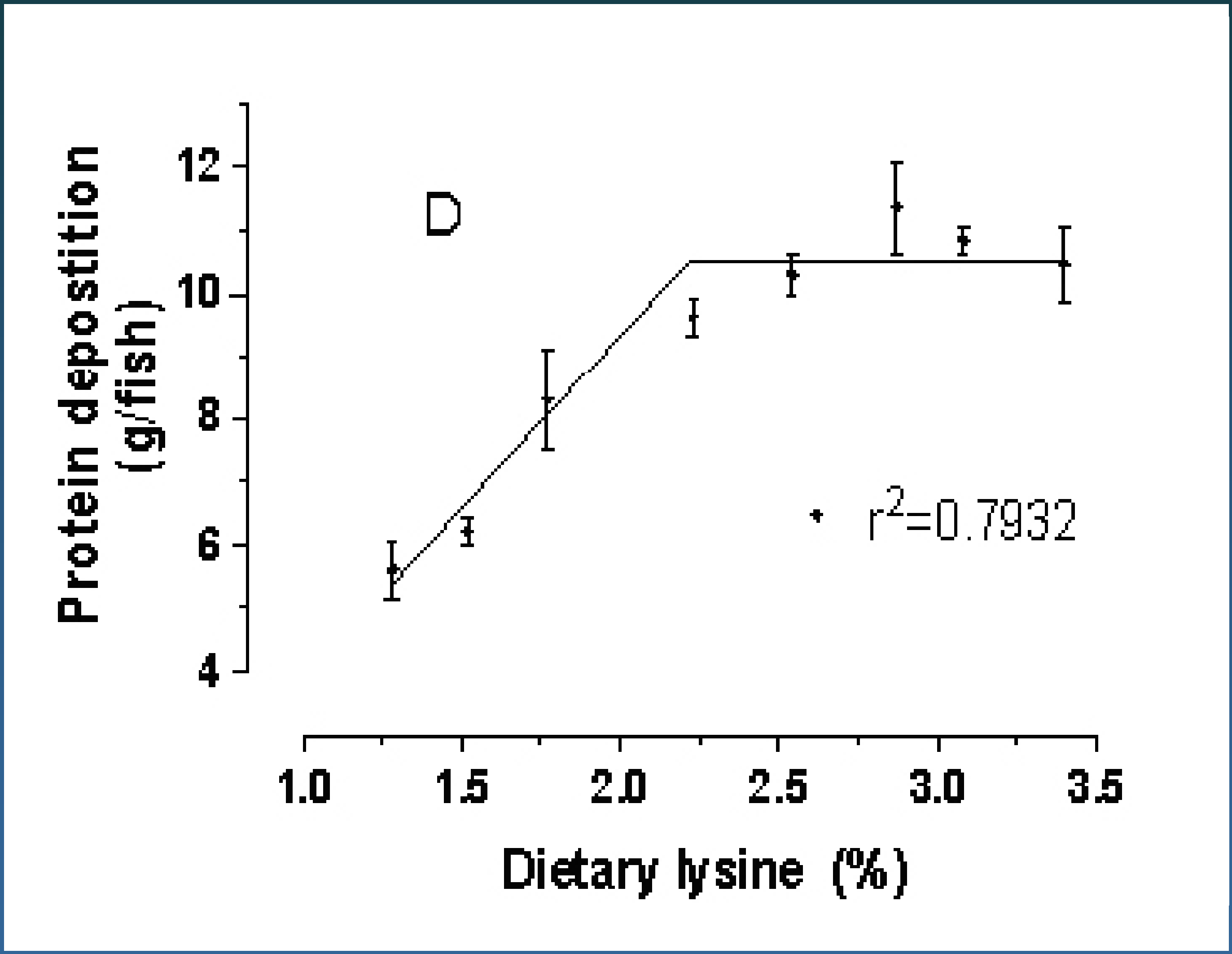
Results

Criteria: **Live weight gain** **Model:** **Four parameter logistic**



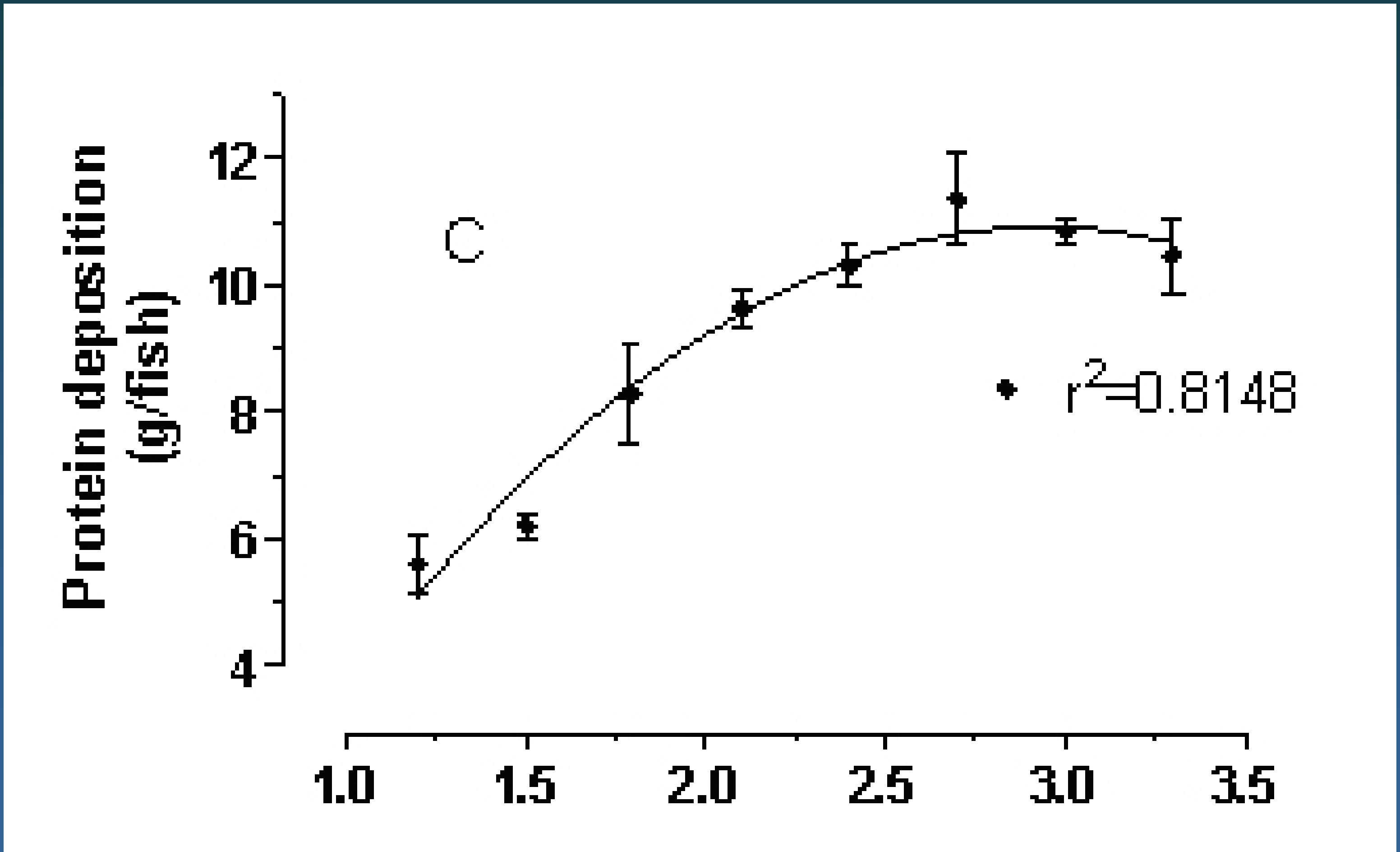
Results

Criteria: **Protein Deposition** **Model:** **Broken-line**



Results

Criteria: **Protein Deposition** **Model:** **Quadratic**



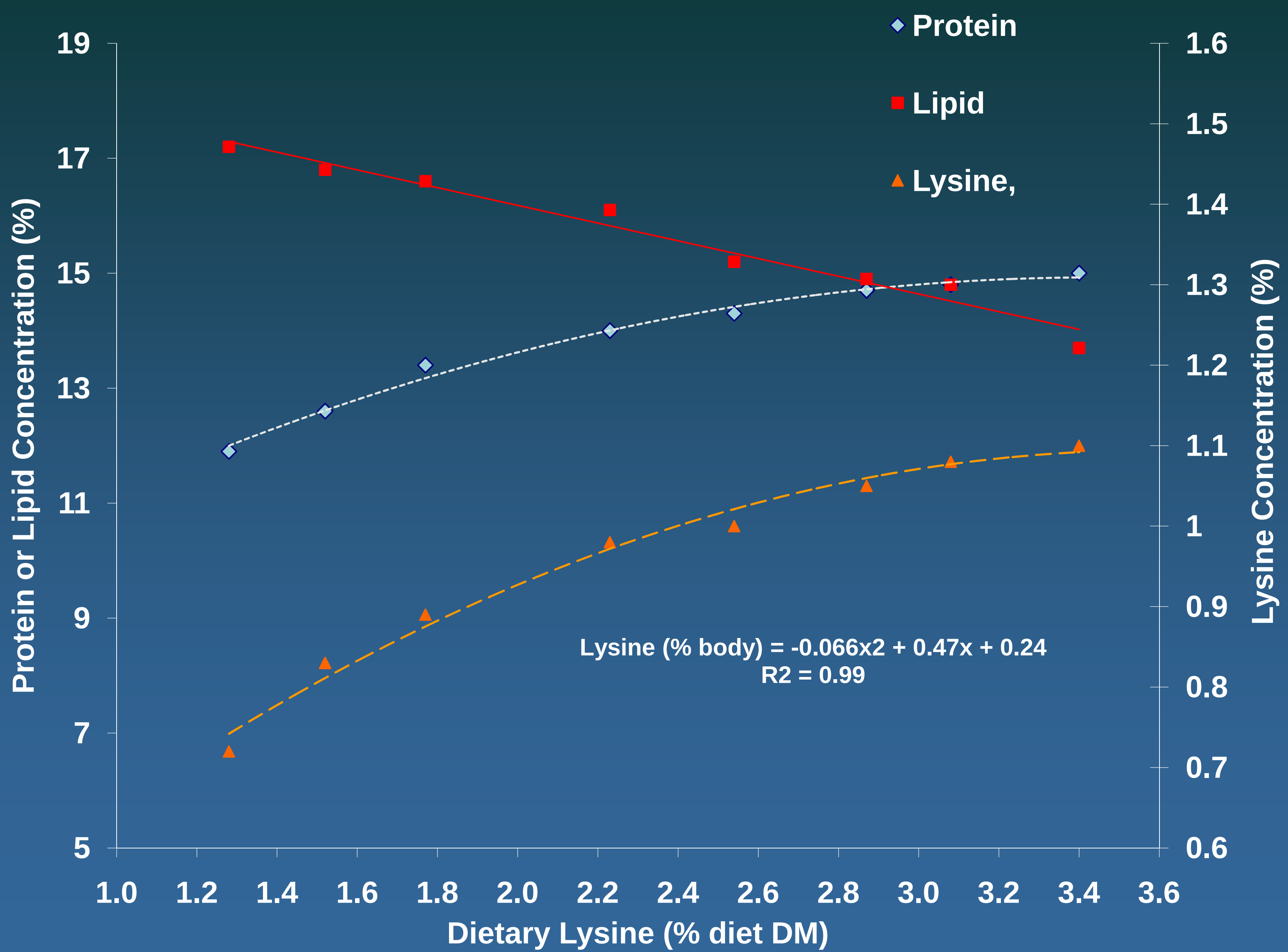
Results

	Model			
Criteria	**Four parameter logistic**	**Exponential**	**Polynomial**	**Broken line**
Weight gain	2.11	2.68	2.23	2.19
Protein deposition	2.44	3.15	2.41	2.22

Use of different response fitting models resulted in very different estimates of lysine requirements

With the exception of broken line model, estimates of lysine requirement for protein gain appear to be 5-15% higher than those for live weight gain

Results



Protein
Lipid
Lysine,
Protein or Lipid Concentration (%)
Lysine Concentration (%)
Dietary Lysine (% diet DM)
Lysine (% body) = -0.066x2 + 0.47x + 0.24
R2 = 0.99
19
17
15
13
11
9
7
5
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
3.4
3.6

Conclusions

Results from this study suggests that lysine requirement for maximum protein gain of rainbow trout is slightly higher than that for maximizing weight gain.

However, model used for fitting the data has a greater impact on estimate of lysine requirement than the criteria selected.

Increasing dietary lysine levels appear to increase whole body protein and lysine concentrations. This could impact flesh quality and fillet yield.

Central Questions

How reliable are estimates of amino acid requirements found in the reference literature (e.g. NRC, 1993)?

What the best mode of expression of essential amino acid requirements?

How does composition of the diet affect essential amino acid utilization and requirements?

How does fish species, life stage, growth rate, feed efficiency, etc. affect utilization and requirement of essential amino acids?

Too Many Questions, Too Little Time!

Perhaps We Need a Better Approach!

Close to 300 studies published on the essential amino acid requirement of fish have already been published

Probably 3 times more have been carried out but not published

Why reinvent the wheel?

May be we simply need to re-analyze existing data?

Why not carry out meta-analysis and look at the effect of fish species, diet composition, growth rates, achieved feed efficiency, etc.

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Protein and amino acid nutrition and metabolism in fish *S J Kaushik and I Seiliez* Aquaculture Research, 2010, **41**, 322–332

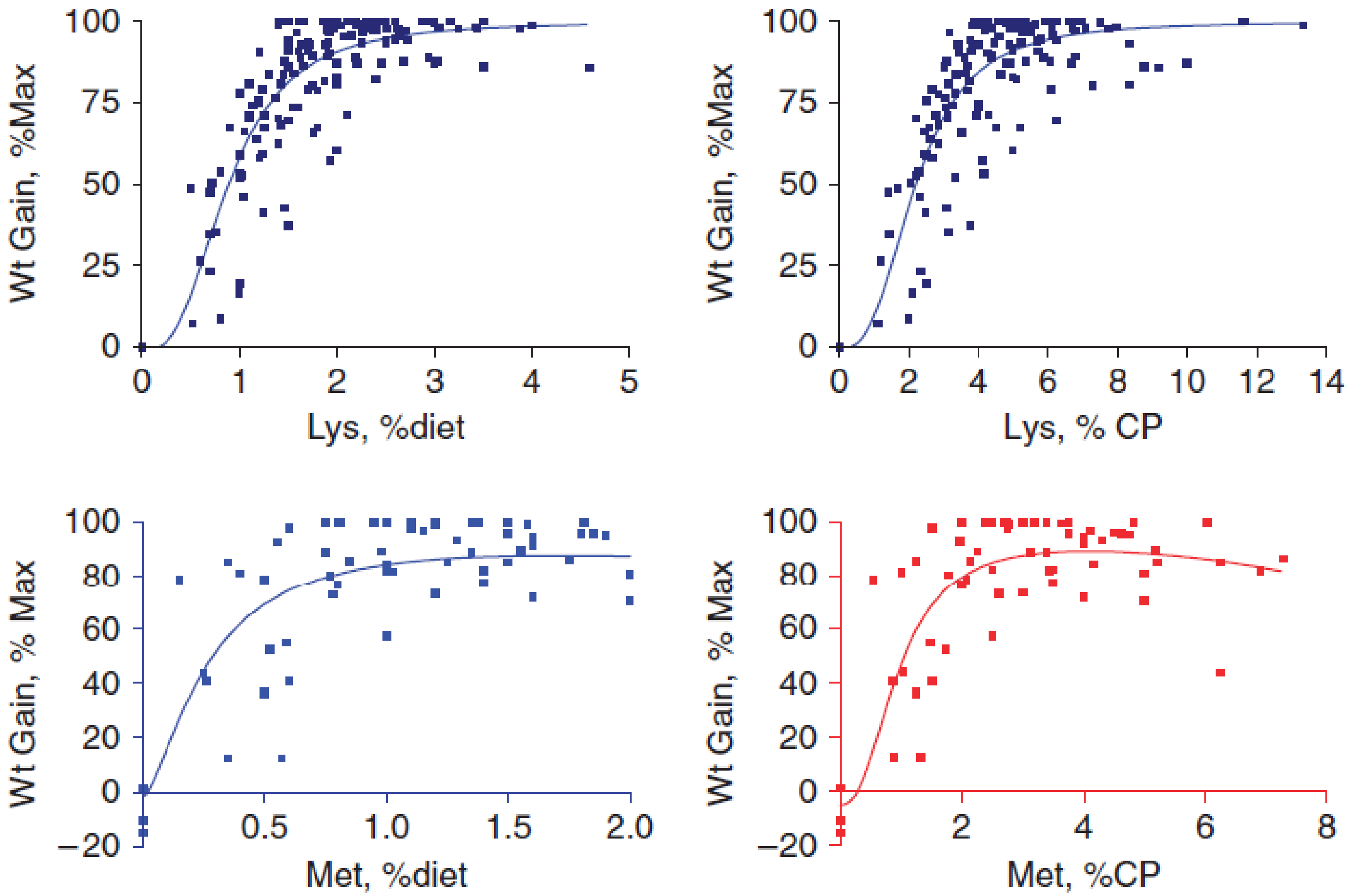
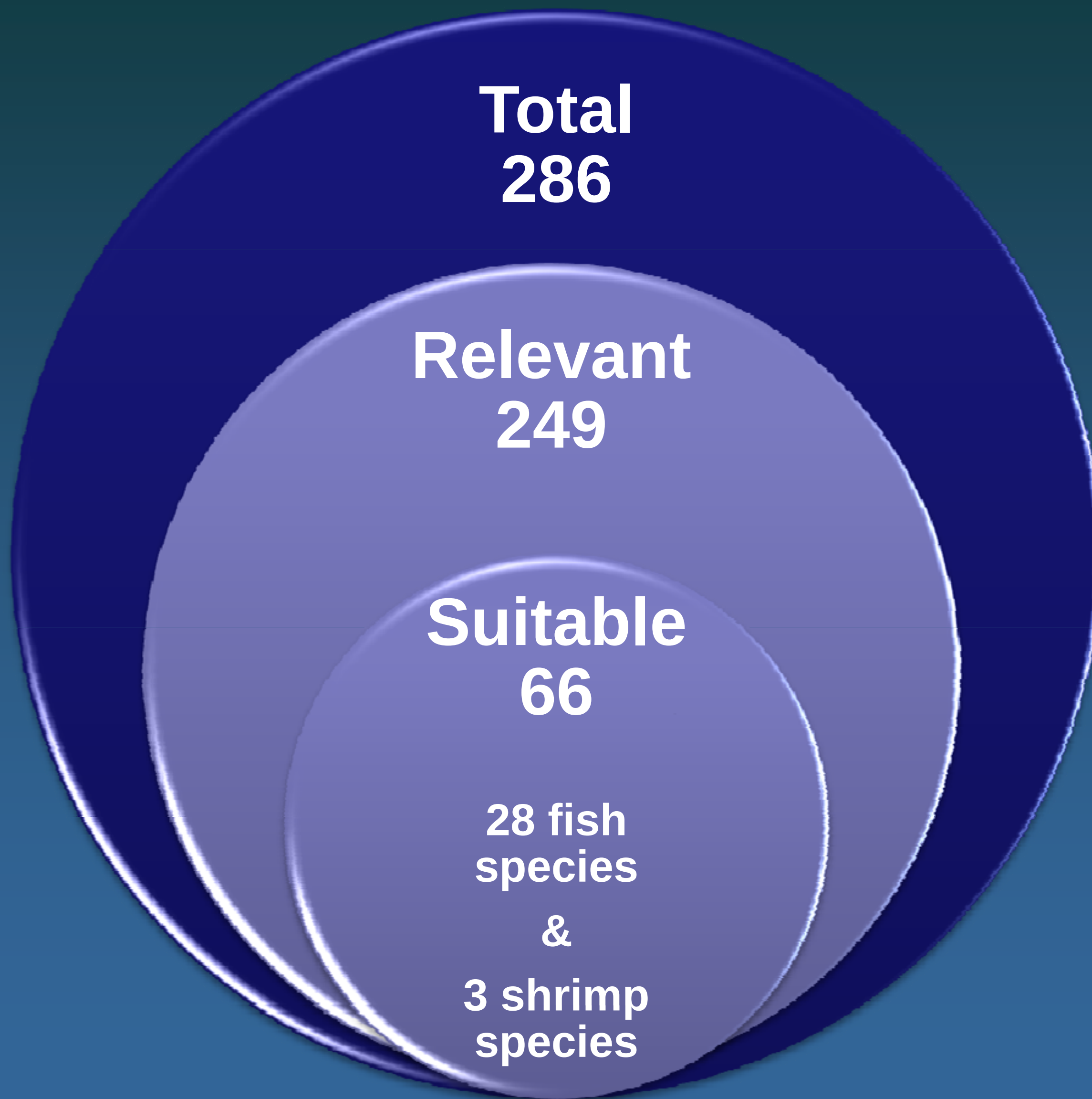


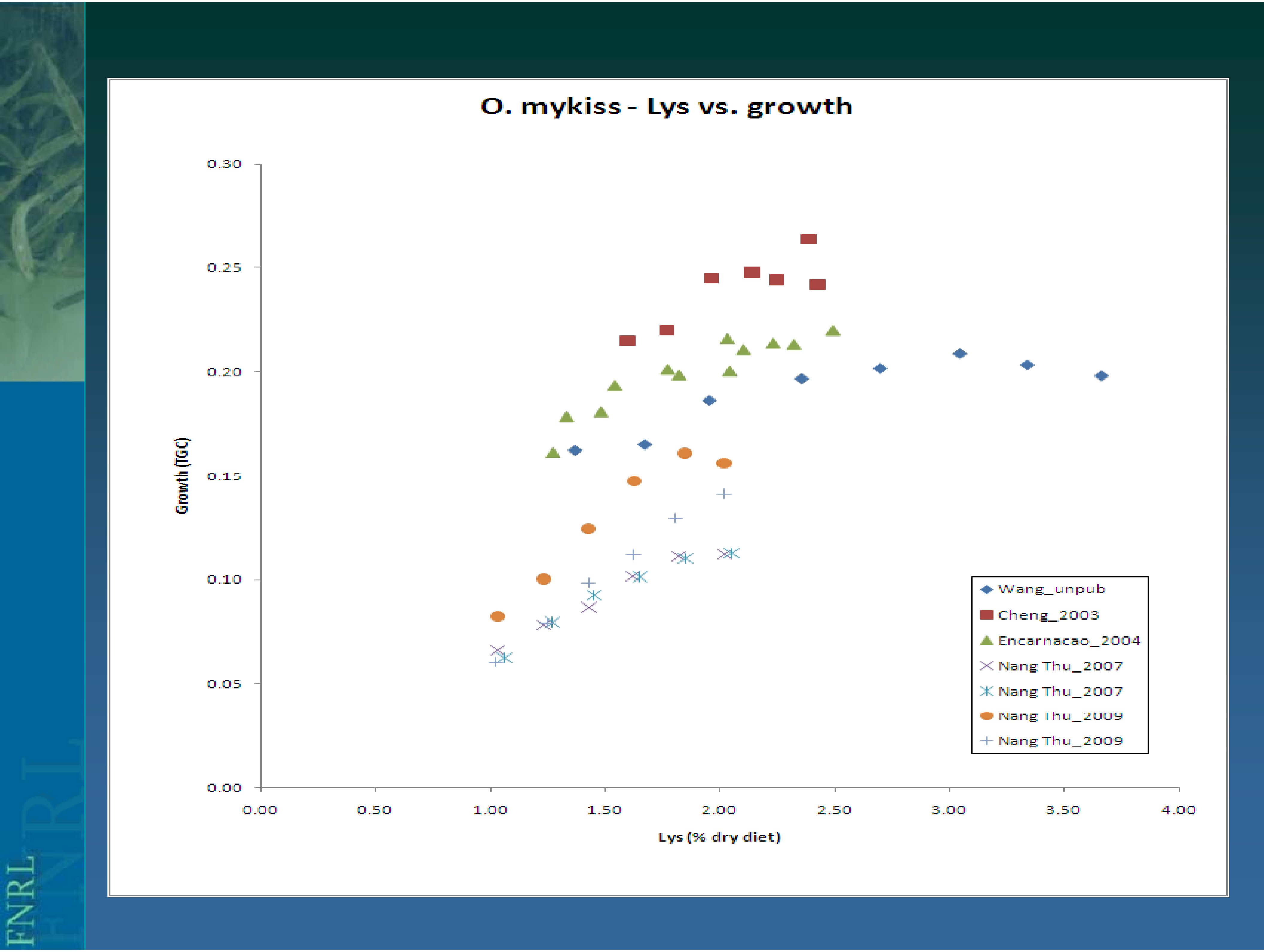
Figure 1 Analysis of literature data on lysine and methionine requirements of different species of fish and shrimp.

Meta-Analysis of Essential Amino Acid Requirements of Fish

- <25% studies met criteria!
- Main reasons for rejection
  - Experimental design
    - Too few graded EAA levels
  - Poor growth
  - Low treatment differences
  - Missing information



Salze, Hua, Quinton, Bureau (in progress)


O. mykiss - Lys vs. growth
Growth (TGC)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
Lys (% dry diet)
Wang_unpub
Cheng_2003
Encarnacao_2004
Nang Thu_2007
Nang Thu_2007
Nang Thu_2009
Nang Thu_2009
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Dynamic Computation of Essential Amino Acid Requirements through the Use of Factorial Requirement Models

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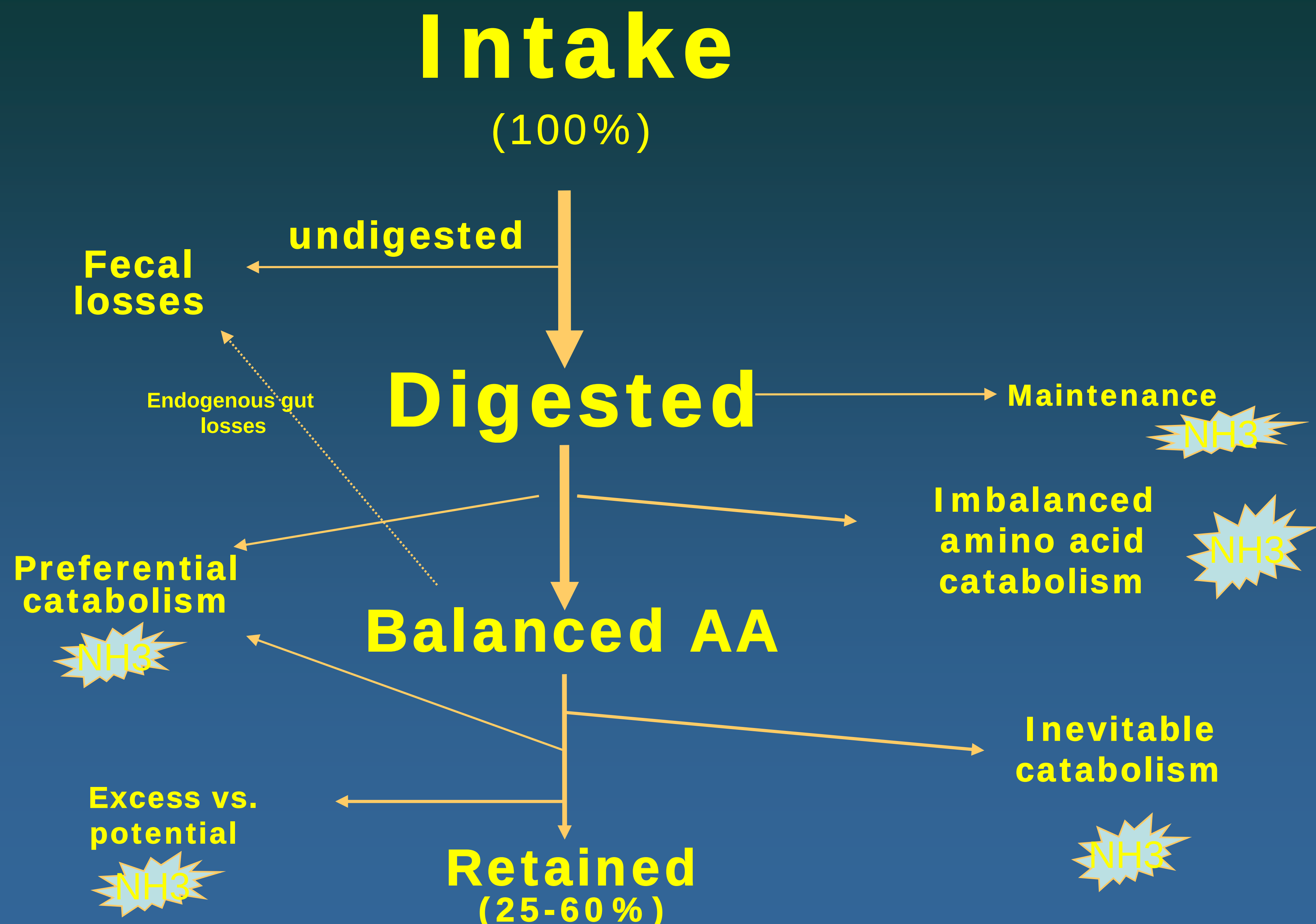
Factorial Essential Amino Acid Requirement Models

- Based on factorial partitioning scheme for essential amino acids
  - Example: Moughan (2002)
- Compute requirement as the sum of amount of essential amino acid (e.g. lysine) deposited and lost through maintenance, inevitable catabolism and digestion
- Generates absolute estimates of essential amino acid requirements (e.g. mg per fish per day)
- This absolute amount is converted into a dietary concentration (a relative amount) on the basis of the expected feed efficiency / feed intake of the animal

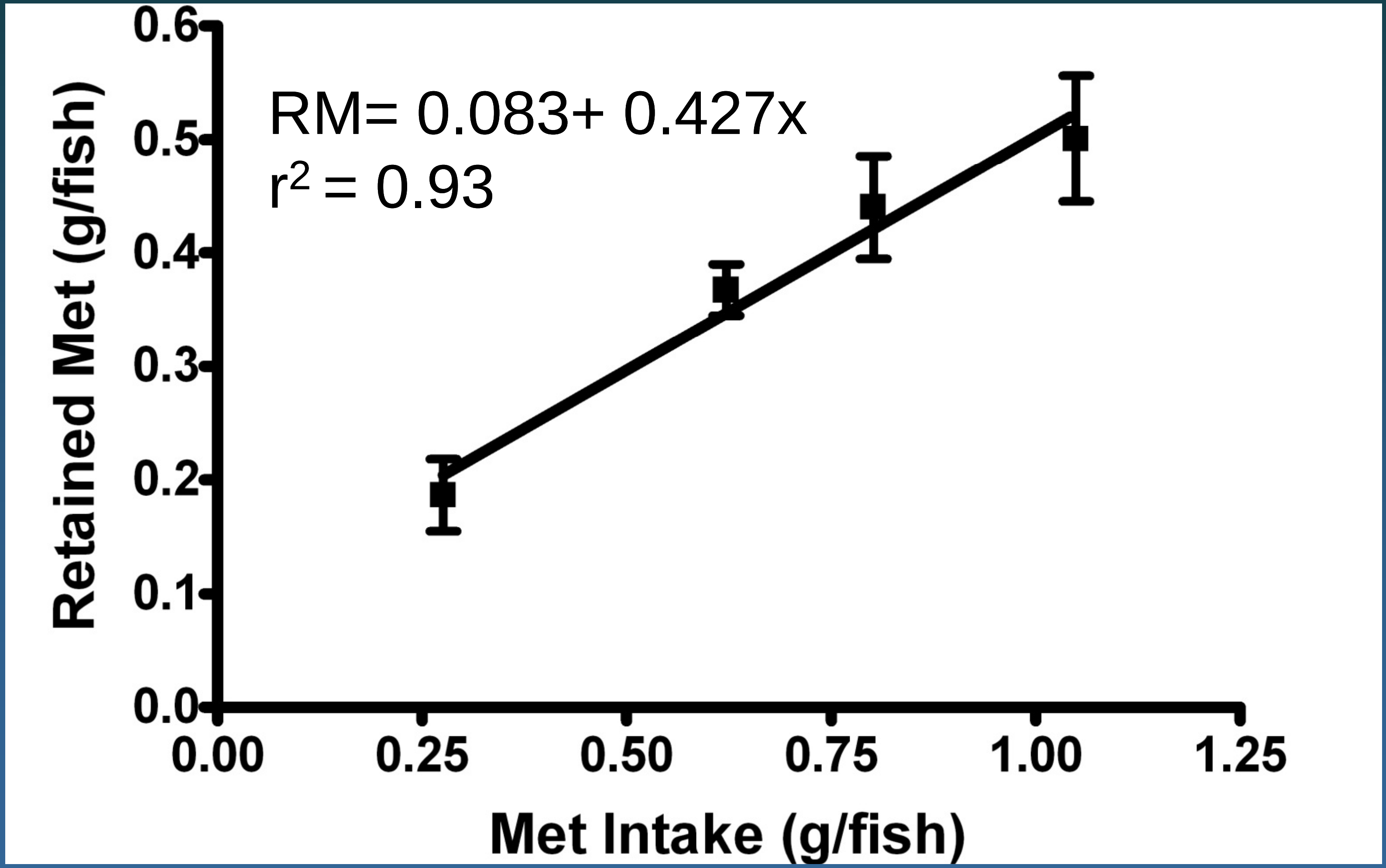
Factorial Model of Amino Acid Utilization



Amino Acid Composition (g/16 g N) of Various Fish and Shrimp Species

	Rainbow Trout	Atlantic Salmon	Channel Catfish	Largemouth bass	European Sea Bass	Gilthead Seabream	Turbot	Penaeid Shrimp
Alanine	6.6	6.5	6.3	6.0	6.8	6.8	7.3	5.6
Arginine	6.4	6.6	6.7	8.5	7.5	8.8	7.7	7.4
Asparate	9.9	9.9	9.7	11.8	9.5	9.4	10.3	8.8
Cysteine	0.8	1.0	0.9	0.8	1.0	1.0	1.1	0.8
Glutamate	14.2	14.3	14.4	13.3	15.5	15.1	16.5	16.2
Glycine	7.8	7.4	8.1	7.8	8.1	7.9	9.7	9.0
Histidine	3.0	3.0	2.2	2.1	2.6	2.7	2.5	2.5
Isoleucine	4.3	4.4	4.3	4.0	4.3	4.3	4.3	3.6
Leucine	7.6	7.7	7.4	8.0	7.1	7.3	7.5	6.5
Lysine	8.5	9.3	8.5	8.1	7.9	8.1	8.1	7.8
Methionine	2.9	1.8	2.9	2.6	2.7	3.0	3.4	2.3
Phenylalanine	4.4	4.4	4.1	4.0	4.3	4.7	4.5	3.6
Proline	4.9	4.6	6.0	6.0	5.3	5.3	5.5	8.0
Serine	4.7	4.6	4.9	4.2	4.5	4.5	5.2	3.6
Threonine	4.8	5.0	4.4	4.4	4.4	4.6	4.6	3.8
Tryptophan	1.0	0.9	0.8	0.9	N/A	N/A	N/A	N/A
Tyrosine	3.4	3.5	3.3	2.8	3.9	4.0	4.1	7.5
Valine	5.1	5.1	5.2	4.6	4.7	4.8	4.7	5.1

Efficiency of Methionine Utilization



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

Factorial Essential Amino Acid Requirement Models

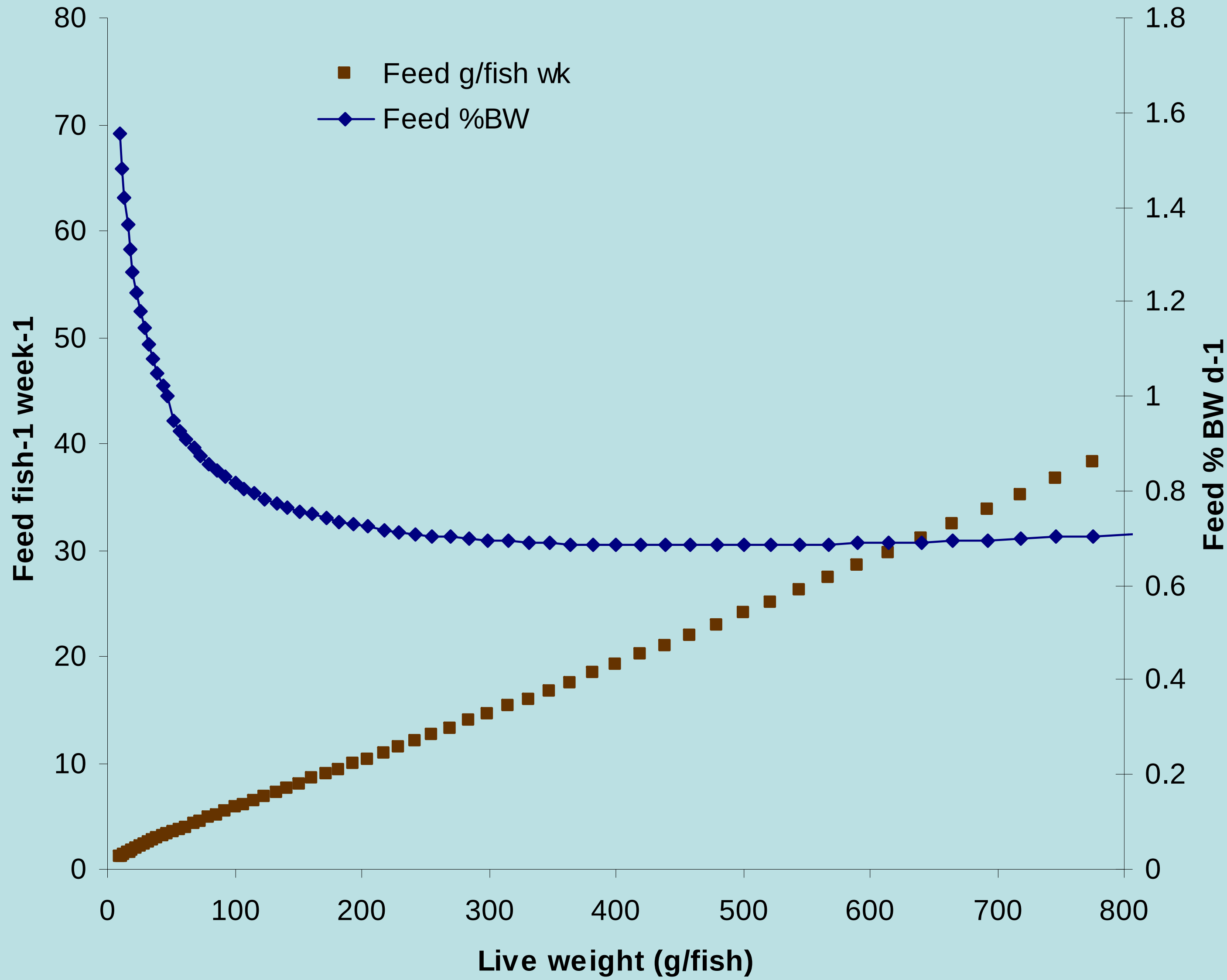
- Based on factorial partitioning scheme for essential amino acids
  - Example: Moughan (2002)

- Compute requirement as the sum of amount of essential amino acid (e.g. lysine) deposited and lost through maintenance, inevitable catabolism and digestion

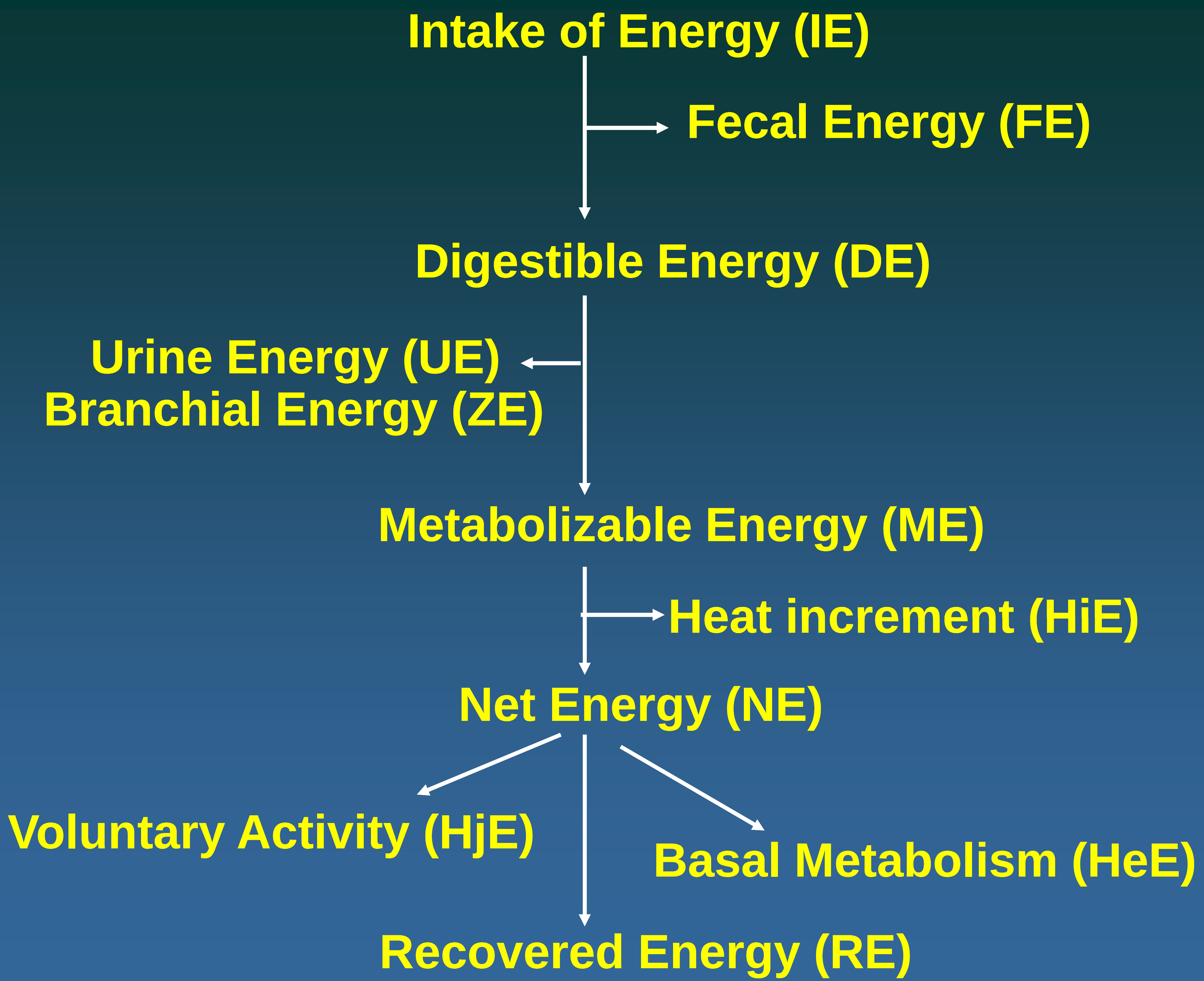
- Generates absolute estimates of essential amino acid requirements (e.g. mg per fish per day)

- This absolute amount is converted into a dietary concentration (a relative amount) on the basis of the expected feed efficiency / feed intake of the animal

Estimated Feed Intake of Rainbow Trout

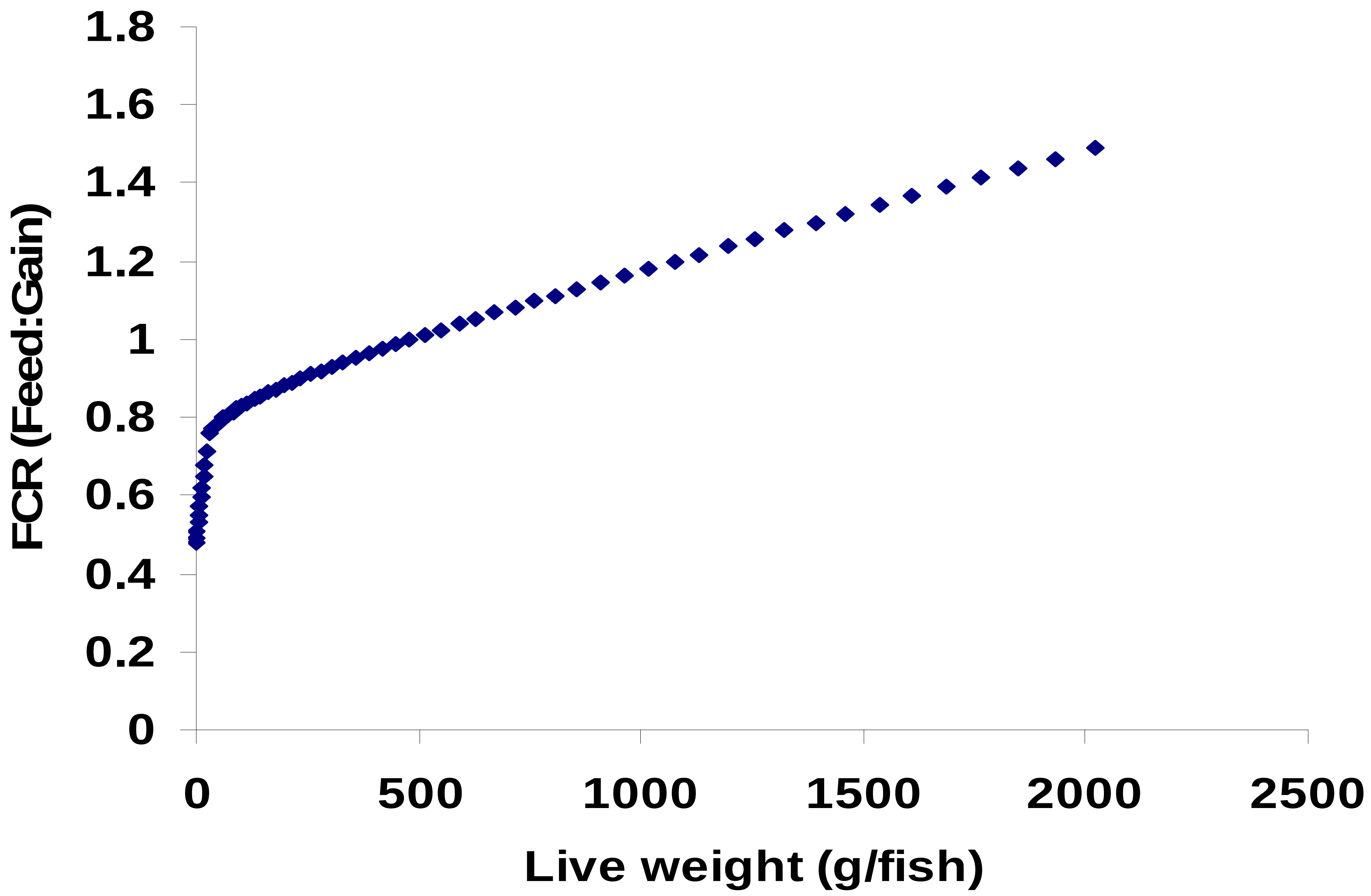


(TGC= 0.180, Temperature = 9°C, Diet 18 MJ DE, 22 g DP/MJ DE) Bureau et al. (2002)



Intake of Energy (IE)
Fecal Energy (FE)
Digestible Energy (DE)
Urine Energy (UE)
Branchial Energy (ZE)
Metabolizable Energy (ME)
Heat increment (HiE)
Net Energy (NE)
Voluntary Activity (HjE)
Basal Metabolism (HeE)
Recovered Energy (RE)

Simulation of FCR of rainbow trout at different weights



Bureau et al. (2008)

Digestible EAA Requirements (% Diet Dry Matter) Estimated Using a Factorial Model for Rainbow Trout of Different Weights Fed Diets with 4.78 Mcal DE (20 MJ DE)

	Weight Class		
Essential Amino Acids	0.2–20 g	20–500 g	500–1,500 g
	% diet DM		
Arg	1.91	1.77	1.62
His	0.83	0.77	0.69
Ile	1.27	1.19	0.98
Leu	2.26	2.11	1.78
Lys	2.47	2.31	1.92
Met + Cys	1.32	1.23	1.10
Phe + Tyr	2.49	2.33	1.82
Thr	1.77	1.63	1.60
Trp	0.43	0.40	0.42
Val	1.90	1.76	1.64

Observations

Current models compute independent estimates of EAA requirements and assume no effect of composition of the diet and life stage of the animal and that feed intake and feed efficiency are determinant factors unrelated to efficiency of EAA utilization

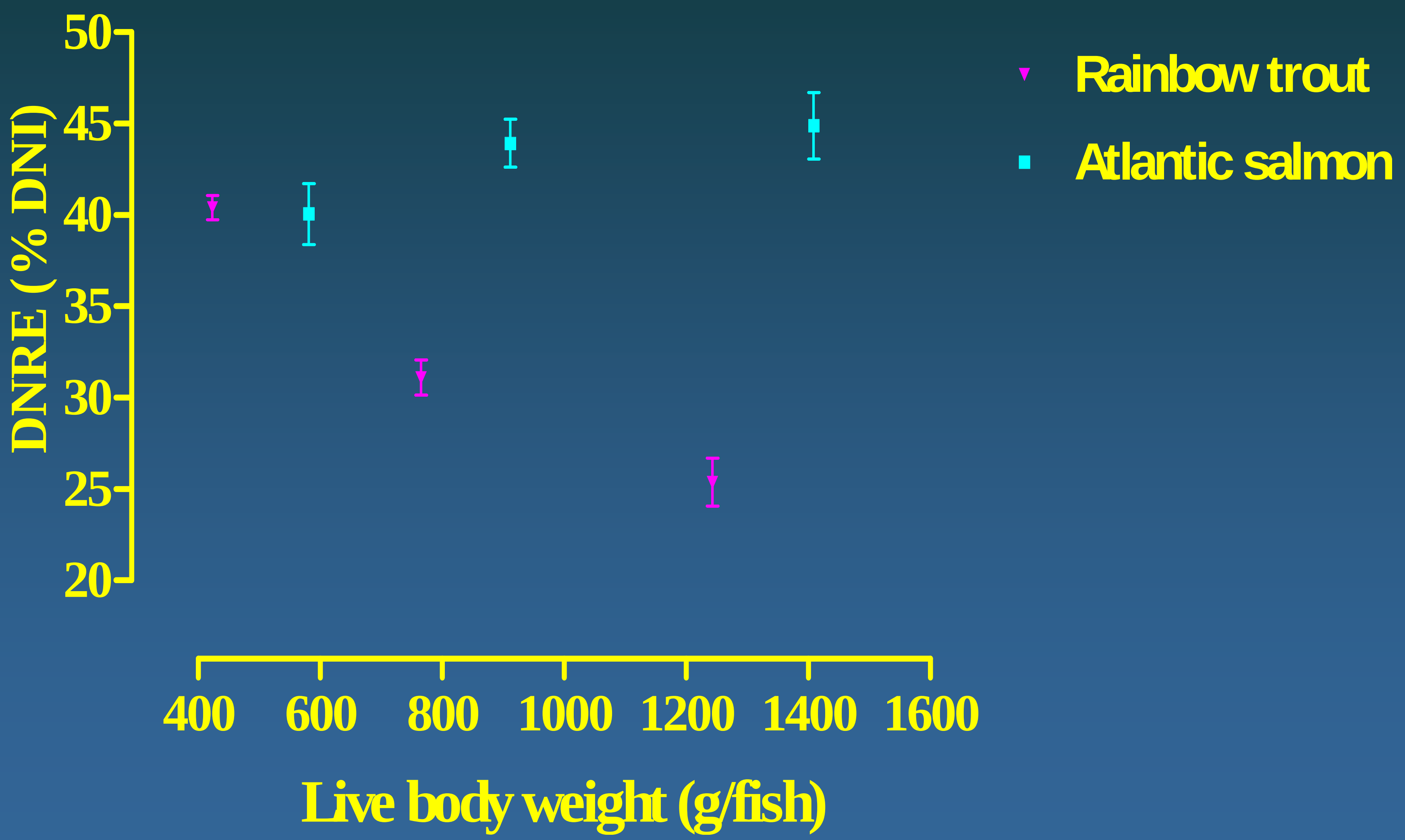
The simple model derived from monogastric animals (poultry and swine) are too simplistic and do not adapt perfectly to fish

Endogenous factors (species and life stage) appear to have as great impact on efficiency of amino acid utilization than dietary manipulations.

Different energy-yielding nutrients (digestible energy sources) have different effect on efficiency of protein and lysine utilization

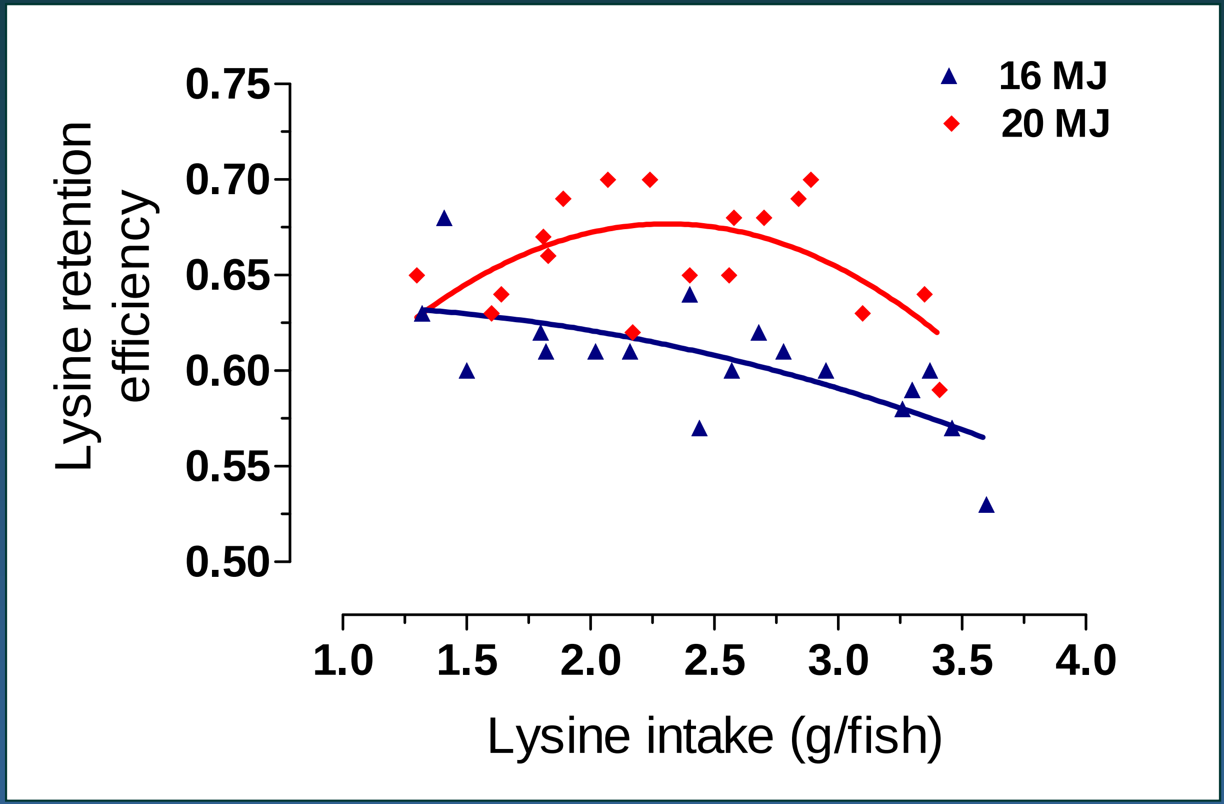
Fish have an endogenously determined target for protein and lipid deposition and they will eat / metabolize feed nutrients to achieve this target. Efficiency of protein utilization is largely determined by the animal itself, not the human feeding this animal

Efficiency of N retention is affected by size in rainbow trout



RESULTS

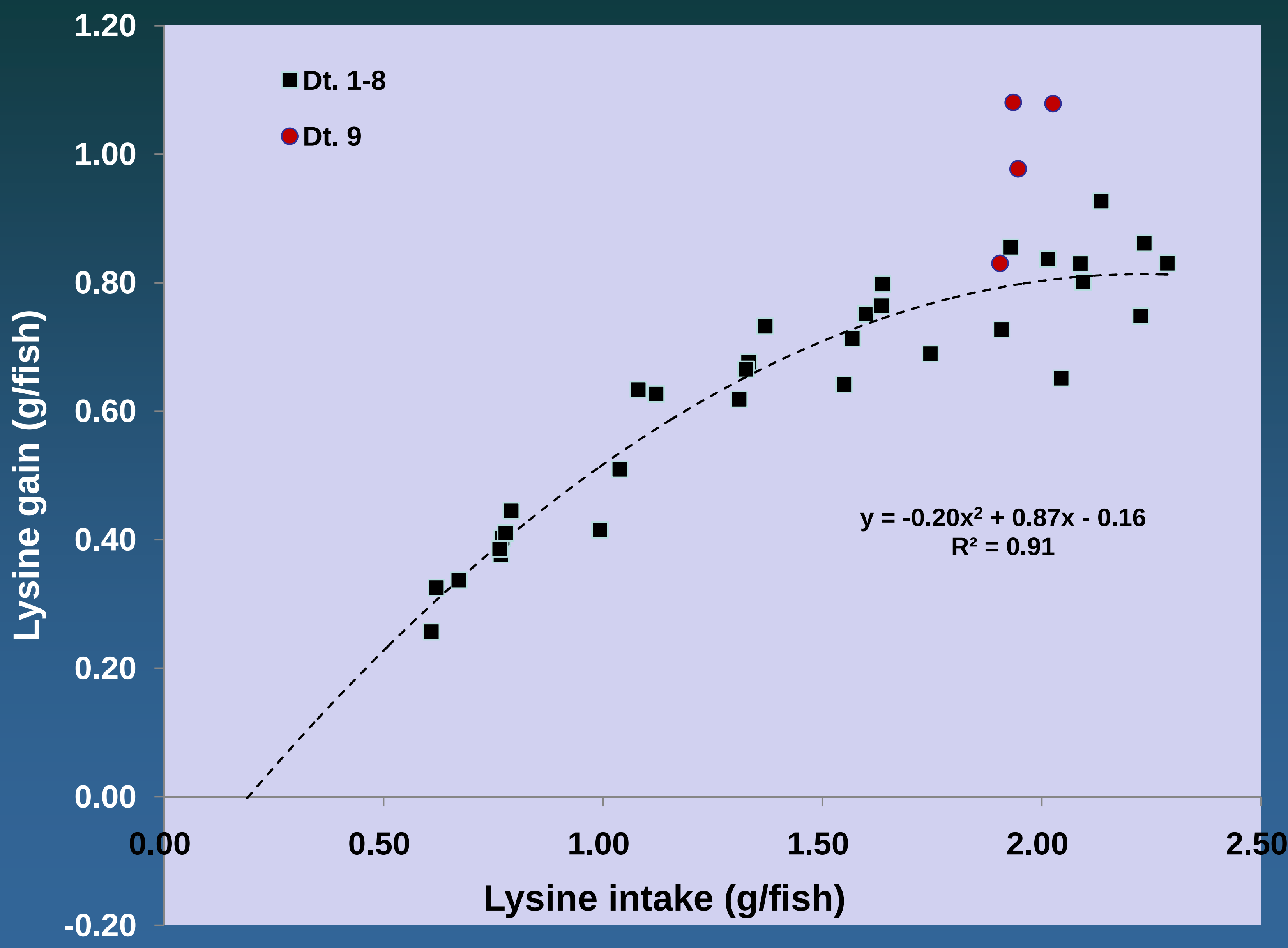
Fig. 3 – Lysine efficiency in response to the lysine intake of fish.



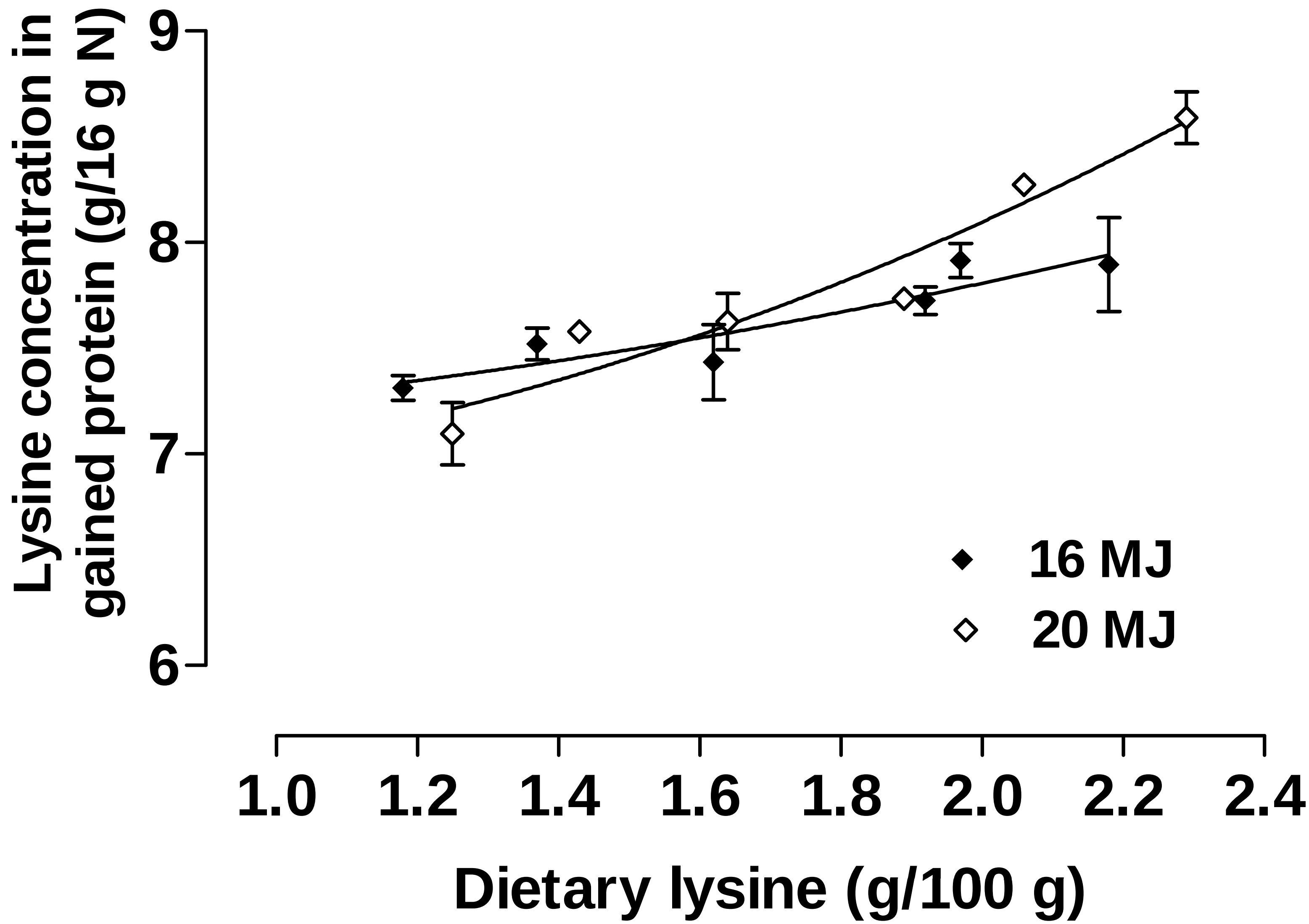
- ✓ Higher efficiency of lysine utilization at higher dietary DE levels.

FNRL

Lysine Deposition as a Function of Lysine Intake

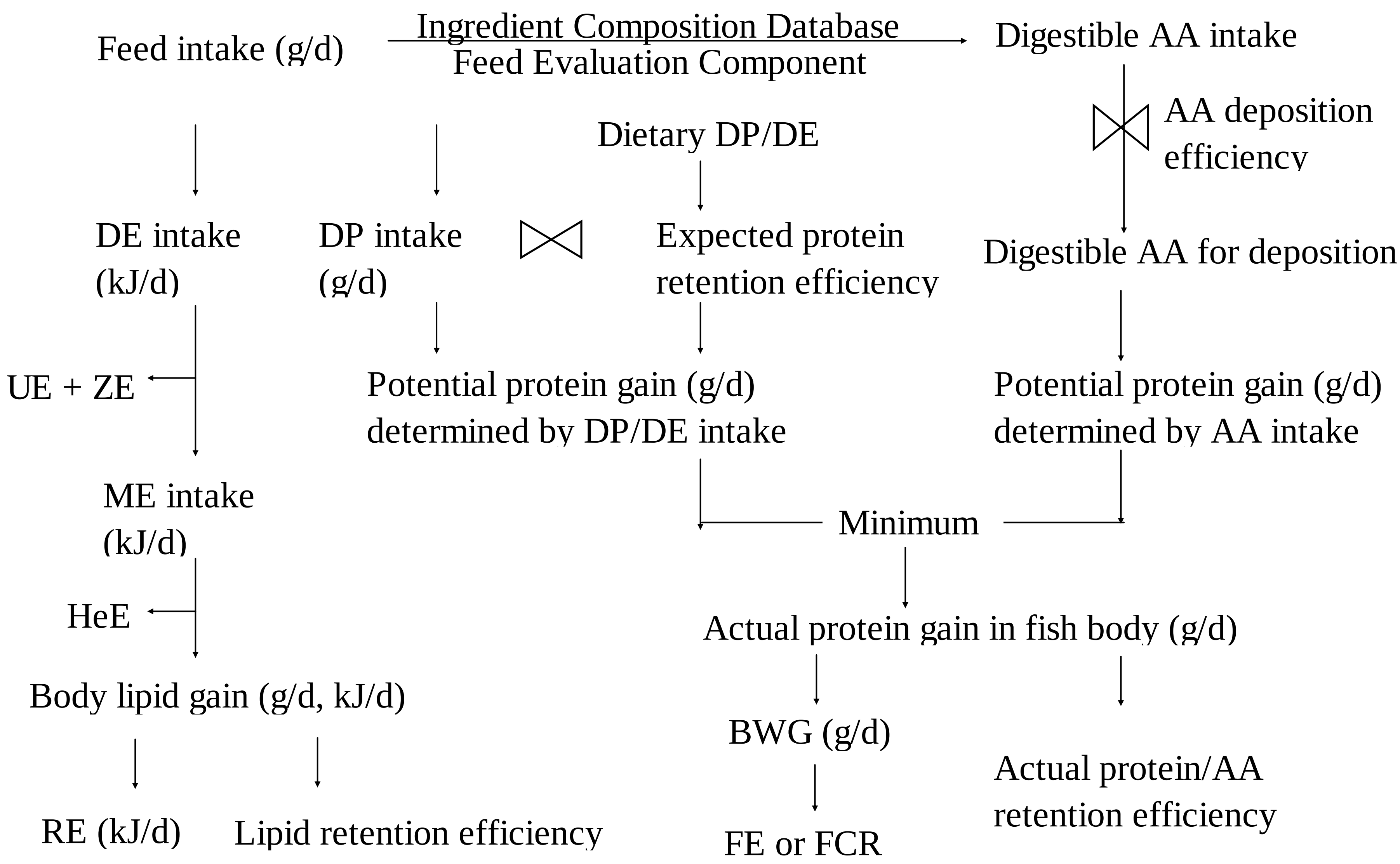


Results



FNRL

A Novel Hybrid Nutrient-Flow Bioenergetics Growth Model for Fish

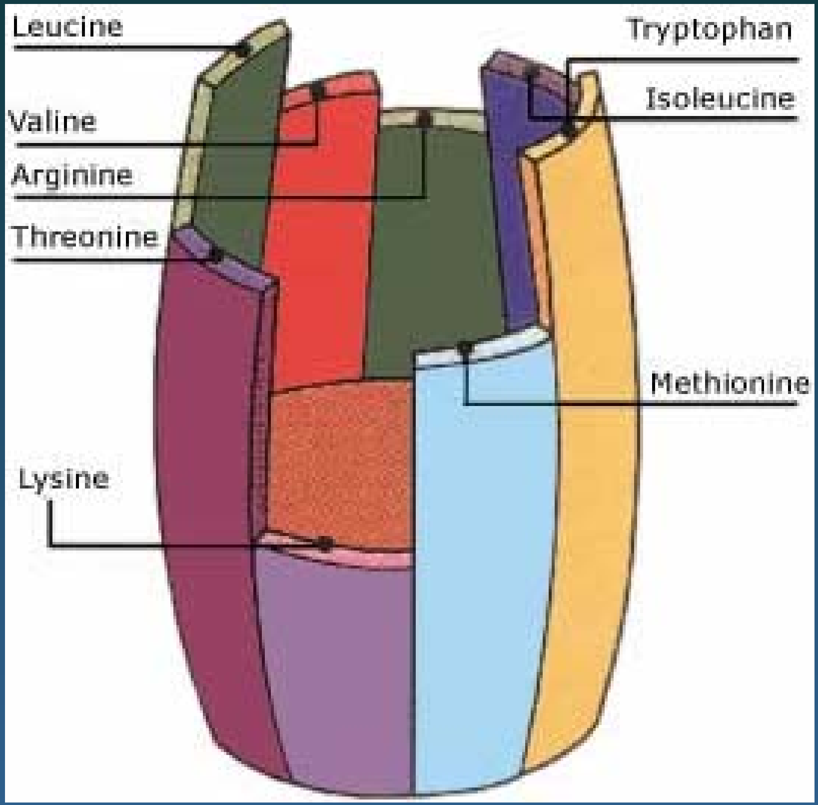


Hua and Bureau (in progress)

Ideal Protein Concept

FNRL

Liebig's Law of the Minimum



Efficiency of Amino Acid Utilization will not be higher than lowest stave

At origin of the concept of "Ideal Protein Pattern"

Profile exactly meeting all essential amino acid requirements
No EAA in excess in comparison to one another

Rainbow trout feeds (35% CP, 15% lipid) formulated to have different ideal protein patterns

Table 5. Study 2: Essential amino acid concentrations (g kg^{-1} dry feed) of experimental diets

Amino acid	Diet			
	1) RT	2) NRC	3) Nonlinear model	4) EAA deletion
Arginine	16.0	17.3	11.5	16.8
Histidine	7.4	8.1	5.7	6.4
Isoleucine	10.8	10.4	13.5	9.9
Leucine	19.0	16.1	13.4	17.5
Lysine	21.2	20.7	27.4	19.3
Methionine	7.2	9.0	7.9	8.1
Cystine	2.0	2.5	3.0	2.2
Phenylalanine	10.9	11.7	11.2	13.7
Tyrosine	8.4	9.0	8.6	10.5
Threonine	11.9	9.2	10.3	12.3
Tryptophan	2.3	2.3	2.0	2.1
Valine	12.7	13.8	15.5	11.2
Total	130.0	130.0	130.0	130.0

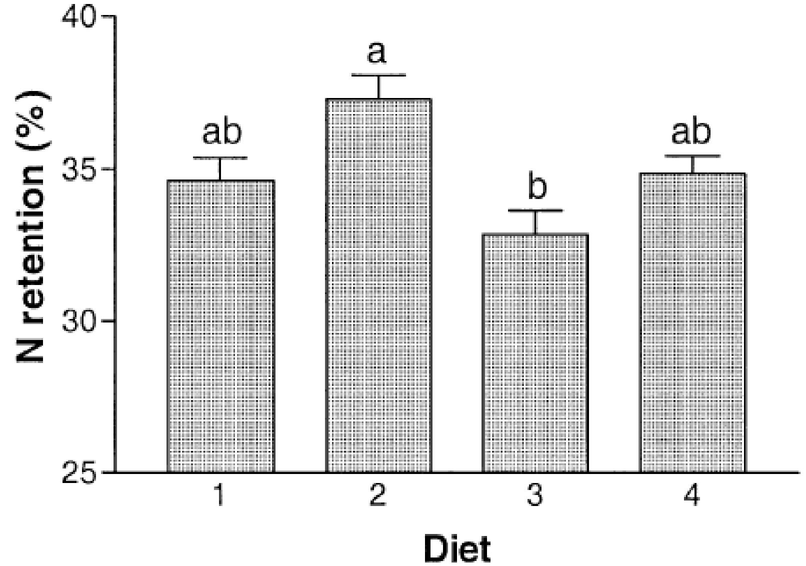


Figure 3. Study 2: Mean N retention (% of N intake) of rainbow trout fed four experimental diets. Error bars indicate SE (n=4). Values not sharing the same letter are significantly different ($P<0.05$, Tukey test).

"Ideal amino acid pattern" derived from NRC (1993) gave best nitrogen retention efficiency.

Green and Hardy (2002)

However, results are interesting but not conclusive…

Table 7. Study 2: Mean weight gain, thermal-unit growth coefficient (TGC) and feed efficiency ratio (FER) of rainbow trout fed four experimental diets (mean ± SE, n=4). Values in the same column not sharing the same superscript are significantly different ($P<0.05$, Tukey test)

Dietary treatment	Gain (g)[1]	TGC	FER
1) RT	23.3 ± 0.4^{ab}	0.102 ± 0.001^{ab}	0.735 ± 0.014^{ab}
2) NRC	24.6 ± 0.4^{a}	0.106 ± 0.001^{a}	0.763 ± 0.006^{a}
3) Nonlinear model	21.9 ± 0.6^{b}	0.098 ± 0.002^{b}	0.690 ± 0.011^{b}
4) EAA deletion	23.2 ± 0.4^{ab}	0.101 ± 0.001^{ab}	0.722 ± 0.011^{ab}

[1] Mean initial weight per fish ± SE for all treatments = 15.5 ± 0.6 g.

Growth and feed efficiency values obtained were relatively low

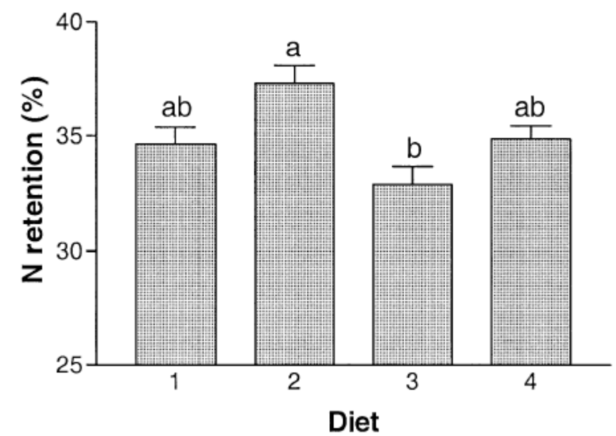


Figure 3. Study 2: Mean N retention (% of N intake) of rainbow trout fed four experimental diets. Error bars indicate SE (n=4). Values not sharing the same letter are significantly different ($P<0.05$, Tukey test).

Nitrogen retention efficiency was relatively low

Deficiency in amino acids may explain the results

Diets used were likely deficient

Table 5. Study 2: Essential amino acid concentrations (g kg^{-1} dry feed) of experimental diets

Amino acid	Diet			
	1) RT	2) NRC	3) Nonlinear model	4) EAA deletion
Arginine	16.0	17.3	11.5	16.8
Histidine	7.4	8.1	5.7	6.4
Isoleucine	10.8	10.4	13.5	9.9
Leucine	19.0	16.1	13.4	17.5
Lysine	21.2	20.7	27.4	19.3
Methionine	7.2	9.0	7.9	8.1
Cystine	2.0	2.5	3.0	2.2
Phenylalanine	10.9	11.7	11.2	13.7
Tyrosine	8.4	9.0	8.6	10.5
Threonine	11.9	9.2	10.3	12.3
Tryptophan	2.3	2.3	2.0	2.1
Valine	12.7	13.8	15.5	11.2
Total	130.0	130.0	130.0	130.0

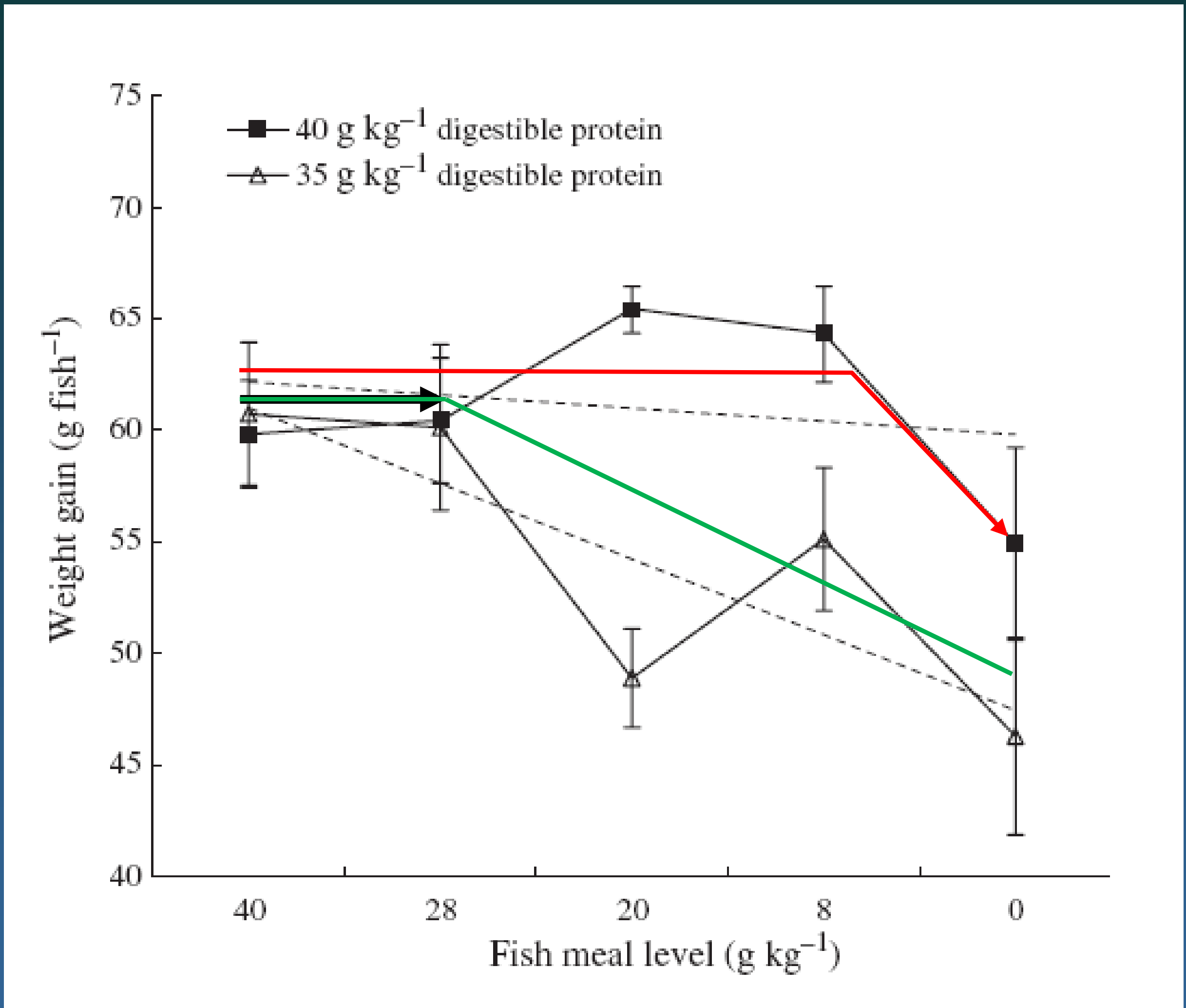
Marginally Deficient in Iso, Cys

Marginally Deficient in Lys

Deficient in Arg, His

Marginally Deficient in Lys, His, Iso

Effect of replacement of high quality protein by a lower quality one at two different protein levels



At higher protein levels, essential amino acid deficiencies occur at lower fish meal (higher alternative ingredient) levels. It is the essential amino acid intakes that matter, not the fish meal level or “relative level” of essential amino acids of the diet

What is more important?

Meeting absolute amino acid requirement (mg/fish per day, % diet)?

<u>or</u>

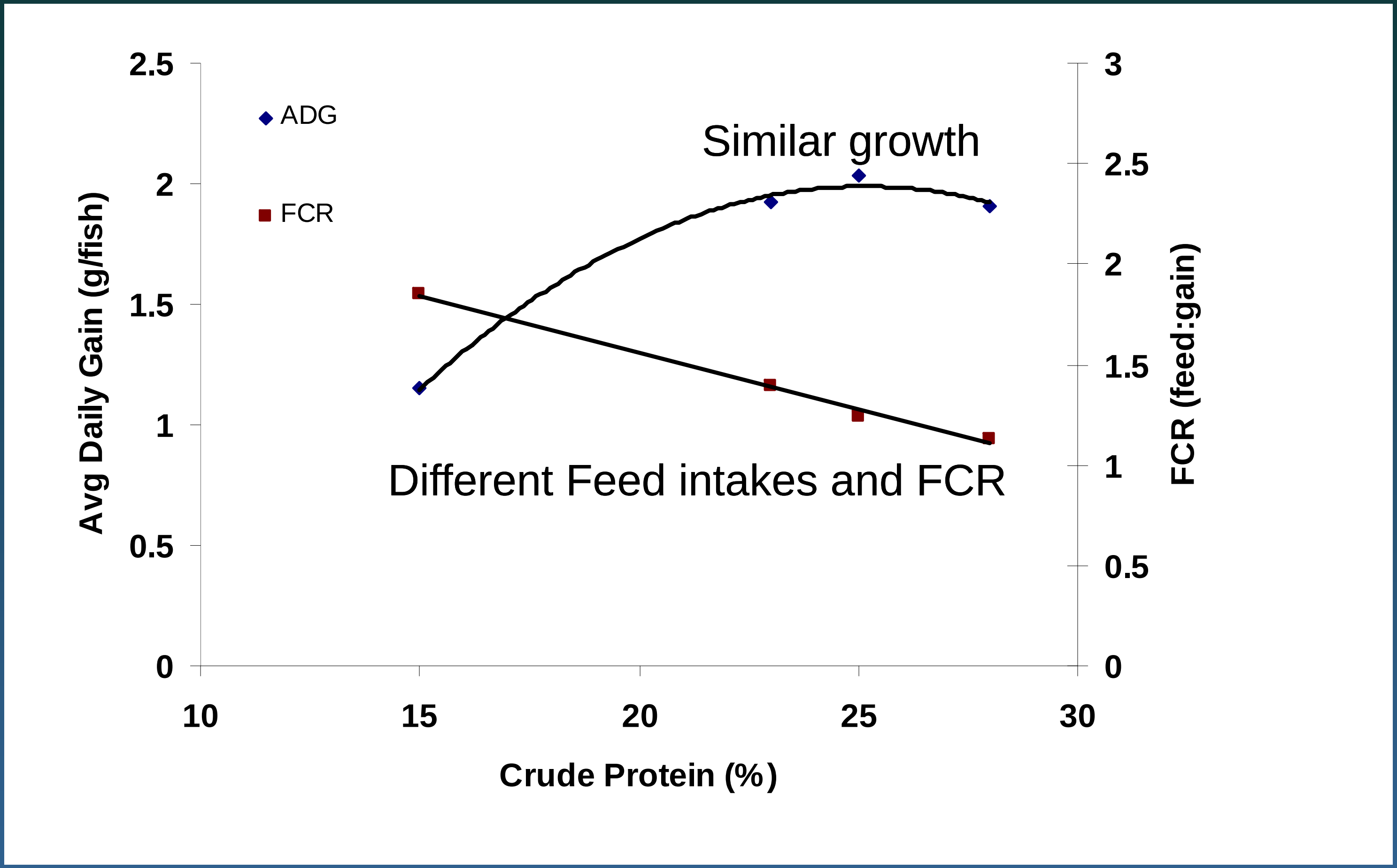
Meeting amino acid requirements as function of all other amino acid supplied?

Usefulness of Ideal Protein Concept

Predicting requirements for 10 EAA when only information on requirements for one or two EAA is available

Formulating low protein diets (diets meeting exactly EAA requirement of fish and have no EAA in excess

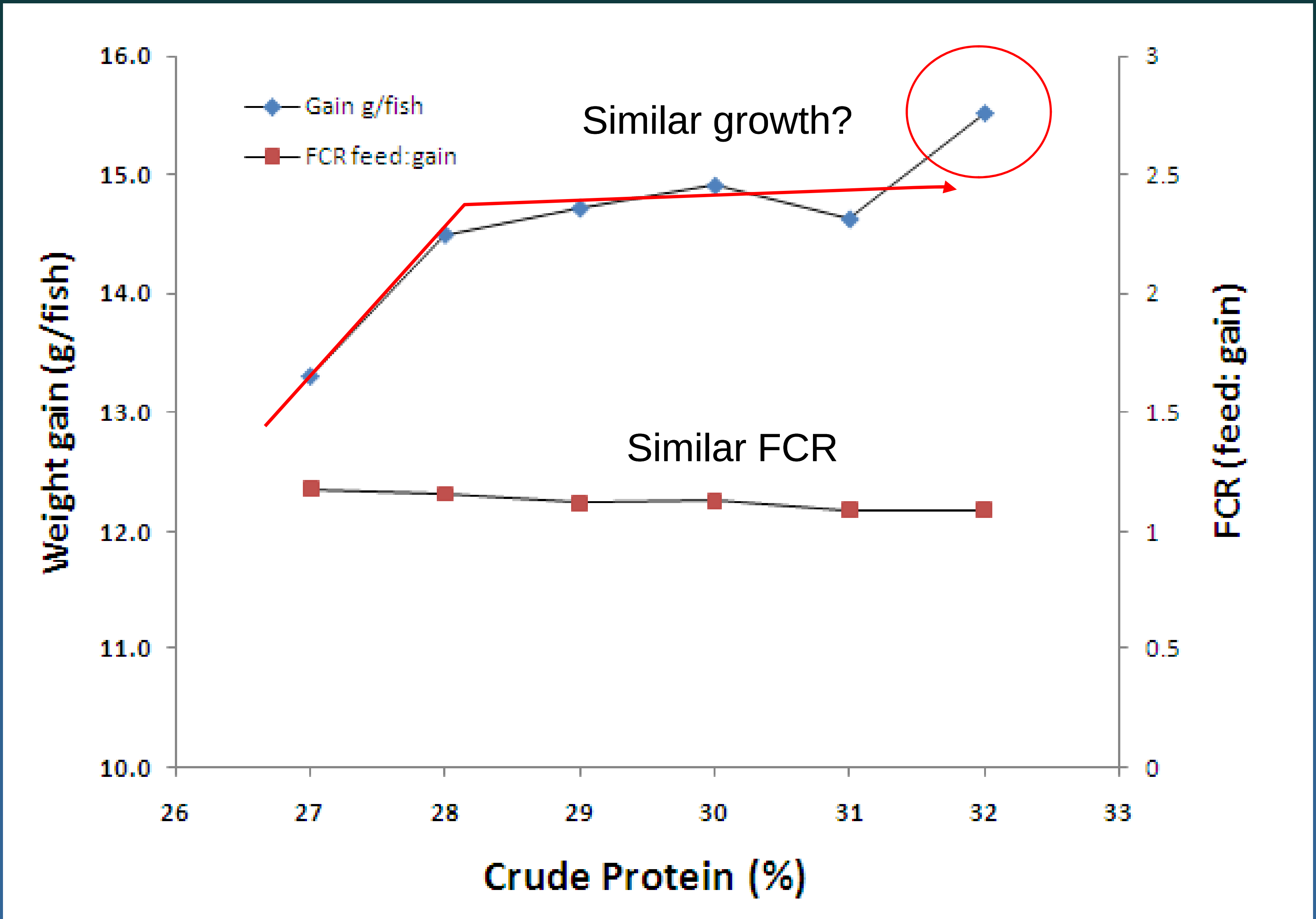
Daily Weight Gain and Feed Conversion Ratio of Nile Tilapia Fed Commercial Feeds with Different Nutrient Densities



Fish are capable of eating more of the more "diluted" lower protein feed in order to obtain enough essential amino acids.

What if we supplemented the low protein feeds with enough essential amino acids to meet the requirement (% diet) of the fish?

Protein Requirement of Tilapia fed Diet with Different Protein Levels but Formulated to Ideal Protein Concept



Bomfim et al. (2008)

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Evonik Degussa
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Alma Aquaculture Research Station