Thomas Wilson
Aquaculture Consultant
DSM Nutritional Products Asia Pacific
Thailand
Email: thomas.wilson@fishnutritionexpert.com

Precision Farming And Precision Nutrition: Improving Aquaculture's Efficiency

Abstract

The aquaculture industry is currently suffering from rising costs in almost every dimension. Whether we are talking about essential utilities like fuel and electricity, the cost of equipment, the rapidly rising cost of raw materials including transport, the uncertainties of exporting products into inflationary markets, or the cost of feeds. During these challenging situations, we start to find ways to control costs and for solutions.

Improving the efficiency of production is needed, but what are the efficiencies that can be improved? Two major factors that impact a farmer's ability to keep costs down and maximize his profit are the survival rate at harvest, and the money invested in feed which is reflected in the FCR. When we consider that the total cost of feed is the single largest operational expense for aquaculture, finding ways to maximize the efficiency of feed utilization should be of major corn to every aquafeed user today. For various reasons, however, this is easier said than done.

Implementation of precision livestock farming and precision nutrition in the poultry and swine industries has been gaining momentum around the world for a while, deploying artificial intelligence systems integrated with sensors to collect precise details about individual feed intake or monitor individual animal health. Growing animals in water makes precision farming more difficult but progress is being made. The aquaculture feed industry is just beginning to understand how to apply precision nutrition for fish and shrimp.

Precision nutrition encompasses up-to-date manufacturing processes as well as leading-edge concepts of nutrition applied to feed formulation. Feed extrusion technology has developed quickly, with the flexibility to make all types and qualities of aquafeeds to suit every species. Concerning nutrition, at a minimum, we need to have a good grasp of required nutrients for a given species, and we need to know quantitative requirements for amino acids, fatty acids, vitamins, and minerals before we can start talking about precision nutrition for a species. How many species of important farmed fish and shrimp have complete information? Surprisingly few. There are still many unknowns about the utilization of amino acids, lipids, and carbohydrates in metabolic processes of fish and shrimp that limit our ability to be precise.

Beyond this, we need to base formulations on digestible nutrients, and also understand how to compensate for the effects of processing and environment on digestibility. We cannot overlook the importance of health status on animal performance and feed utilization. Factorial modeling of fish growth takes a great amount of time and money, but it provides a great foundation for precision nutrition. Understanding research technologies like nutrigenomics and epigenetics can tell us how nutrients influence gene expression, and how we can nudge gene expression through nutritional programming and immune system priming. Sometimes, due to a lack of complete information, precision nutrition for our animals is beyond our capability. Thus, further R&D investment to fill in major gaps about the nutritional needs of important species is something the aquaculture industry and its supporters needs to commit themselves to do to ensure a sustainable future.

THE AQUACULTURE ROUNDTABLESERIES® 2022

A shared vision for aquaculture in Asia

6 - 7 October 2022 • Ho Chi Minh City • Vietnam

TARS 2022

The Aquaculture Roundtable Series

AQUAFEEDS

A New Equilibrium

Precision Farming & Precision Nutrition

Improving Aquaculture's Efficiency

Thomas Wilson

Independent Aquaculture Nutrition Consultant

Aquaculture as a Sustainable Business

Environment

- Control within the Farm Environment
- Management of Water Quality

Nutrition

- Efficient growth of animals (Optimal health and well-being)
- Acceptable feed conversion ratio (FCR) >>> Biggest factor in controlling profit
- Strong responses to stress and disease challenges >>> High survival maximizes yield >>>> Second biggest factor in controlling profit

Precision Farming

- Livestock
  - Intelligent software monitoring
    - Track Individual Tagged Animals
    - Body Temperature
    - Irregular Behaviour and Movement
    - Sound (Coughing)
    - Feeding Activity
      - Number of animals feeding
      - Birds pecking
      - Feeder loss in weight
      - Individual Feeding

- Aquaculture
  - Intelligent software monitoring
    - Water quality monitoring
    - Aeration control
    - Fish sizing and counting
    - Irregular Movement
  - AI-controlled feeding systems
    - Sense Feeding Activity
      - Cameras
      - Sound
    - Records Feeding Times, Intervals and Duration of Feeding
  - AKVA, AQ1, Umitron (SG)

Precision Aquaculture

Fearghal O'Donncha and Jon Grant

IEEE Internet of Things Magazine • December 2019

- Precision Aquaculture goals defined:
  1. Improve accuracy, precision and repeatability in farm operations
  2. Facilitate more autonomous and continuous biomass/animal monitoring
  3. Provide more reliable decision support
  4. Reduce dependencies on manal labour and subjective assessments

- Basic Requirements - Conditions that must be fulfilled
  - Sensing of the ambient environment
  - Continuous monitoring of animal variables
  - Requires a reliable model to predict how animal variables dynamically vary in response to external factors
  - Observations and predictions integrated into an online system for decision and control

TARS 2022
The Aquaculture Roundtable Series

Precision Aquaculture Nutrition

TARS 2022
The Aquaculture Roundtable Series

1. Make the right feed for the right animal:
   a) Multiplicity of species require feeds with diverse physical properties – density, shape, hardness, texture
2. Efficient production increasingly requires state-of-the-art processes:
   a) Precise control of physical properties
   b) Minimize non-uniformity and non-homogeneous nutrient distribution

Contents lists available at ScienceDirect
Aquaculture Reports
journal homepage: www.elsevier.com/locate/aqrep
ELSEVIER

Precision nutritional regulation and aquaculture

Zhang Yuru[a,b], Lu Ronghua[a,b], Qin Chaobin[a,b], Nie Guoxing[a,b,*]

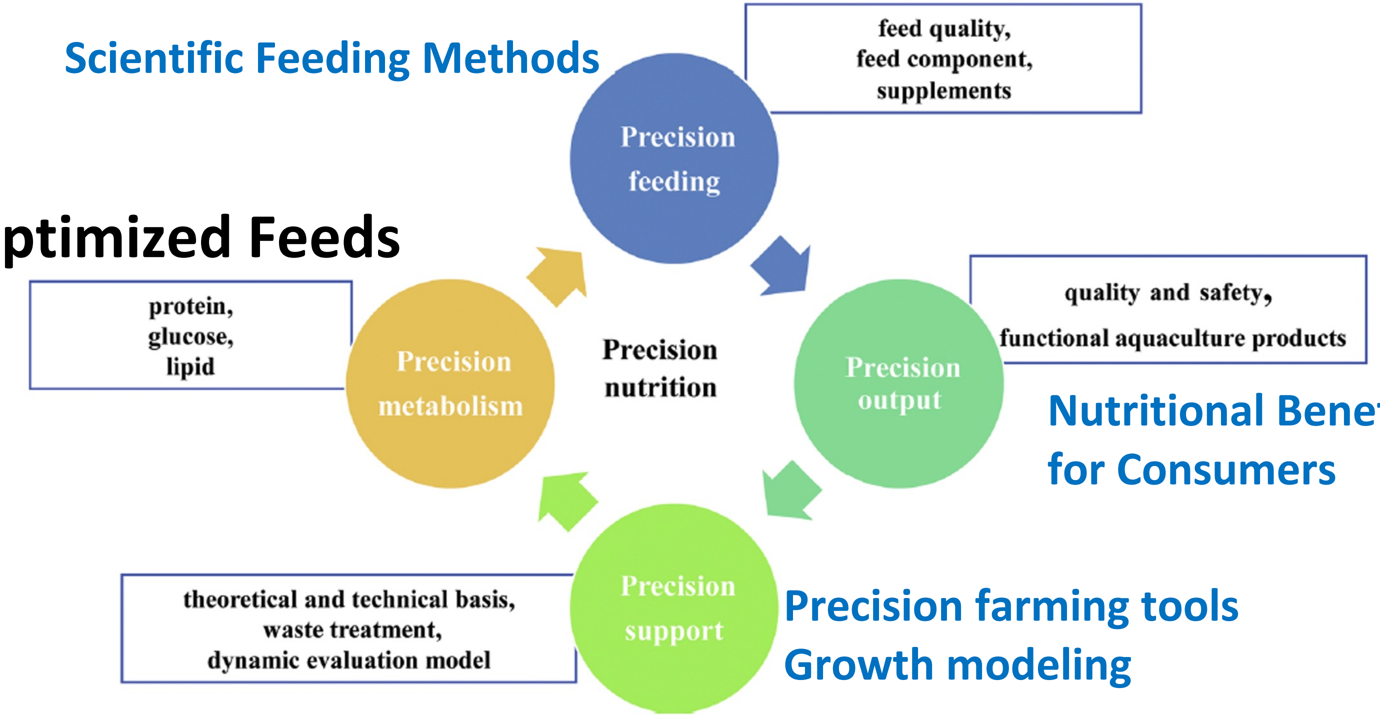
[a] College of Fisheries, Henan Normal University, Xinxiang 453007, PR China
[b] College of Fisheries, Engineering Technology Research Center of Henan Province for Aquatic Animal Cultivation, Henan Normal University, Xinxiang 453007, PR China

Zhang et al. 2020

Precision Nutrition Concepts (Zhang et al. 2020)

Scientific Feeding Methods

Efficient Nutrient-optimized Feeds



Nutritional Benefit for Consumers

Precision farming tools
Growth modeling

"'Precision feeding' refers to the development of the most suitable feed for fish based on species, sex, development stage, water environment and other factors."

"'Precision metabolism' involves identification of genes and pathways that are involved in the metabolism of carbohydrates, lipids, proteins, minerals, vitamins and other nutritional factors."

"'Precision output' refers to products rich in specific nutrients, such as essential fatty acids (EFAs) and essential amino acids (EAAs)."

"'Precision support' is defined as the use and development of various new support infrastructures and technologies that support the healthy and sustainable development of aquaculture."

Efficient Nutrient-optimized Feeds

1. High Quality Ingredients
   - Nutrient composition
   - Processed for maximum nutrient retention
   - High digestibility
   - High nutrient availability to animal

2. There are numerous essential nutrients:
   - **Amino Acids**
     - Independent of source
     - Essential, Non-essential, Conditionally essential
   - **Vitamins**
     - One or multiple vitamins involved in 100% of metabolic pathways
     - In humans, vitamin B_3 (niacin) as NADP(H) is utilized by more than 470 proteins (Penberthy and Kirkland 2020)
   - **Lipids**
     - Most effective energy source
     - Phospholipids
     - Essential fatty acids in membranes
   - **Minerals**
     - Importance often neglected in aqua nutrition
     - Directly influence gene expression
     - Four Zinc atoms in every Ribosome
       - Gene transcription driving protein synthesis
     - Essential co-factors in antioxidant defense

Amino Acid Requirements – Freshwater Fish

2020 Vol. * kg	576 K	3,540 K	2,485 K	4,236 K	5,791 K	3,178 K	4,515 K	454 K	103 K	631 K	2,983 K
2020 Value *	$886 M	$5.41 B	$4.07 B	$8.75 B	$13.25 B	$7.04 B	$9.01 B	$1.09 B	$154 M	$1.2 B	$3.67 B
AMINO ACID	Mrigal Carp	Catla Carp	Rohu Carp	Common Carp	Grass Carp	Big Head Carp	Nile Tilapia	Channel Catfish	African Catfish	Snake head Spp.	Pangas Spp.
Arginine	🟢	🟢	🟡	🟢	🟢		🟢	🟢	🟢		
Histidine	🟢	🟢	🟡	🟢	🟢			🟢	🟢	🟡	
Isoleucine	🟢	🟢	🟡	🟢	🟡		🟢	🟢			
Leucine	🟢	🟢	🟢	🟢	🟡		🟢	🟢			
Lysine	🟢	🟢	🟡	🟢	🟢		🟢	🟢	🟢	🟢	🟡
Methionine	🟢	🟢	🟡	🟢	🟡		🟢	🟢	🟢	🟢	🟡
Phenylalanine	🟢	🟢	🟢	🟢	🟡		🟢	🟢			
Threonine	🟢	🟢	🟢	🟢	🟢		🟢	🟢	🟡	🟡	
Tryptophan	🟢	🟢	🟡	🟢	🟢		🟢	🟢	🟢	🟢	
Valine	🟢	🟢	🟢	🟢	🟡		🟢	🟢	🟡		

🟢 NRC 2011 🟡 not in NRC 2011/after NRC 2011. *FAO FishstatJ

Amino Acid Requirements – Marine Fish

TARS 2022
The Aquaculture Roundtable Series

2020 Volume* kg	282 K	1,361 K	161 K	40.5 K	227 K	1,284 K	117 K	160 K
2020* Value	$1.45 B	$1.36 B	$1.17 B	$104 M	$694 M	$2.04 B	$540 M	$117 M
AMINO ACID	Gilthead Seabream	European Seabass	Yellowtail Spp.	Cobia	Grouper Spp.	Milkfish	Asian Seabass	Pompano Spp.
Arginine	🟢	🟢	🟢	🟢	🟢	🟢	🟢	
Histidine	🟢	🟢	🟡			🟢		
Isoleucine	🟢	🟢				🟢		🟡
Leucine	🟢	🟢				🟢	🟢	🟡
Lysine	🟢	🟢	🟡	🟢	🟢	🟢	🟢	🟡
Methionine	🟢	🟢		🟢	🟢	🟢		🟡
Phenylalanine	🟢	🟢				🟢	🟢	
Threonine	🟢	🟢				🟢	🟢	
Tryptophan	🟢	🟢				🟢		
Valine	🟢	🟢				🟢	🟢	

🟢 NRC 2011 🟡 not in NRC 2011/after NRC 2011 *FAO FishstatJ

AQUAFEEDS
A New Equilibrium

Amino Acid Requirements – Shrimp

2020 Volume * (Kg)	43.7 K	717 K	5,812 K	3,950	334 K
2020 Value *	$375 M	$5.81 B	$33.66 B	$18.6 M	$2.77 B
AMINO ACID	Kuruma Prawn *P. japonicus*	Black Tiger Prawn *P. monodon*	Pacific White Shrimp *P. vannamei*	Indian White Shrimp *P. indicus*	Freshwater Prawn *M. rosenbergii*
Arginine	🟢	🟢	🟡		🟢
Histidine	🟢	🟢	🟡		🟢
Isoleucine	🟢	🟢	🟡		🟢
Leucine	🟢	🟢	🟡		🟢
Lysine	🟢	🟢	🟢		🟢
Methionine	🟢	🟢	🟡		🟢
Phenylalanine	🟢	🟢	🟡		🟢
Threonine	🟢	🟢	🟡		🟢
Tryptophan	🟢	🟢	🟡		🟢
Valine	🟢	🟢	🟡		🟢

🟢 NRC 2011 🟡 not in NRC 2011/after NRC 2011. *FAO FishstatJ

Vitamin Requirements – Freshwater Fish

Vitamin	Mrigal Carp	Catla Carp	Rohu Carp	Common Carp	Grass Carp	Nile Tilapia	Channel Catfish	African Catfish	Indian Catfish	Snakehead Spp.	Pangas Spp.
Thiamin (B1)				🟢			🟢			🟡	
Riboflvin (B2)				🟢		🟢	🟢			🟡	
Nicotinamide (B3)				🟢		🟢	🟢			🟡	
Pyridoxine (B6)						🟢	🟢			🟡	
Cobalamin (B12)						NR	R			🟡	
Biotin				🟢		🟢	R			🟡	
Pantothenic Acid				🟢		🟢	🟢			🟡	
Folic Acid				🟢		🟢	🟢			🟡	
Vitamin C			🟢	🟢		🟢	🟢			🟡	
Vitamin A				🟢		🟢	🟢				
Vitamin D				🟡		🟢	🟢				
Vitamin E				🟢		🟢	🟢			🟡	
Vitamin K				🟡			R				

🟢 NRC 2011 🟡 not in NRC 2011/after NRC 2011

Vitamin Requirements – Marine Fish

AQUAFEEDS
A New Equilibrium

Vitamin	Gilthead Seabream	European Seabass	Yellowtail Spp.	Cobia	Grouper Spp.	Milkfish	Asian Seabass	Pompano Spp.
Thiamin (B1)	R		🟢				R	
Riboflavin (B2)	R		🟢				R	🟡
Nicotinamide (B3)	🟡		🟢					
Pyridoxine (B6)	🟡		🟢				⚫	🟡
Cobalamin (B12)	R		🟢					
Biotin	🟡		🟢					
Pantothenic Acid			🟢				⚫	
Folic Acid			🟢					
Vitamin C	🟢	🟢		🟢	🟢		⚫	🟡
Vitamin A		🟢			🟢	🟡		
Vitamin D		🟡	🟢					
Vitamin E			🟢	🟡	🟢		R	🟡
Vitamin K			🟢					

🟢 NRC 2011 🟡 not in NRC 2011/after NRC 2011

Vitamin Requirements – Shrimp

TARS 2022
The Aquaculture Roundtable Series

Vitamin	**Kuruma Prawn** *P. japonicus*	**Black Tiger Prawn** *P. monodon*	**Pacific White Shrimp** *P. vannamei*	**Indian White Shrimp** *P. indicus*	**Freshwater Prawn** *M. rosenbergii*
Thiamin (B1)	🟢	🟢		🟢	
Riboflvin (B2)	🟢	🟢			
Nicotinamide (B3)	🟢	🟢		🟢	
Pyridoxine (B6)	🟢	🟢	🟢	🟢	
Cobalamin (B12)		🟢			
Biotin		🟢			
Pantothenic Acid		🟢		🟢	
Folic Acid		🟢			
Vitamin C	🟢	🟢	🟢	🟢	🟢
Vitamin A	🟢	🟢			
Vitamin D	🟢	🟢			
Vitamin E	🟢	🟢	🟢		🟢
Vitamin K	R	🟢	🟢		

🟢 NRC 2011 🟡 not in NRC 2011/after NRC 2011

Actions to Improve Efficiencies

- Stop borrowing nutrient data from other species
  - ! It works until it doesn't

- Do the needed requirement studies on amino acids and vitamins
  - University or institutional research supported by Industry
    - Industry Associations (Producers & Processors)
    - Amino acid and Vitamin producers

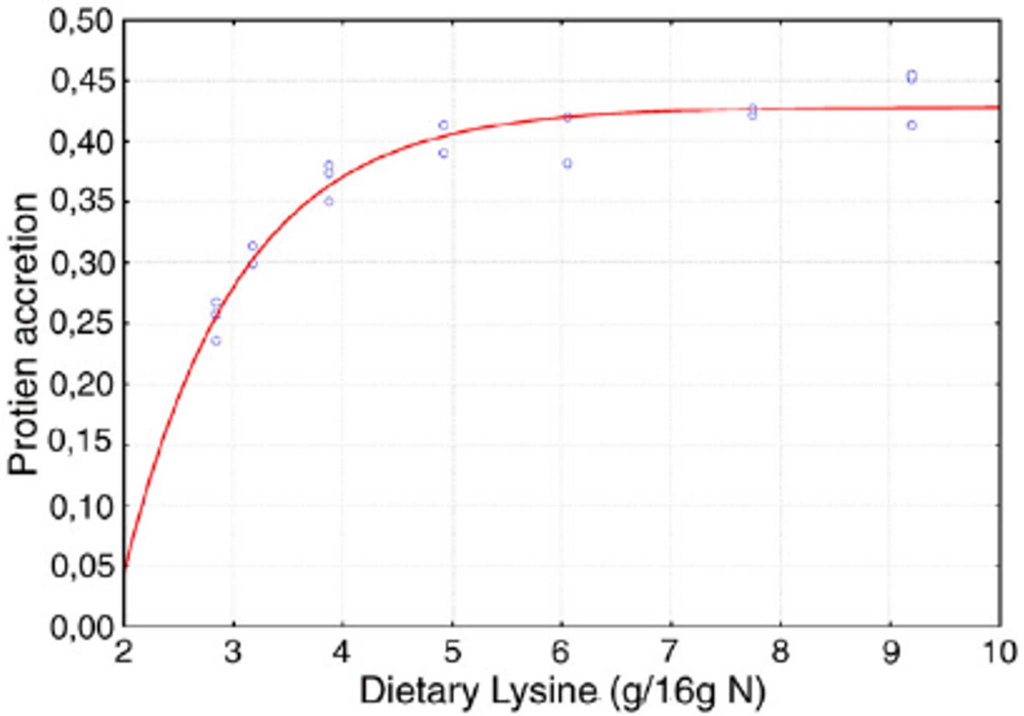
- Shift the requirement paradigm
  - Forget about % of feed basis – that's 1950's thinking
  - Start thinking about nutrients as "Units required/Unit of weight gain"
    - Every kilogram of fresh weight gain is about 200 grams of protein
    - How to provide that 200 grams **of amino acids as protein *from the ingredients you select*** depends on the growth rate (daily/weekly intake)

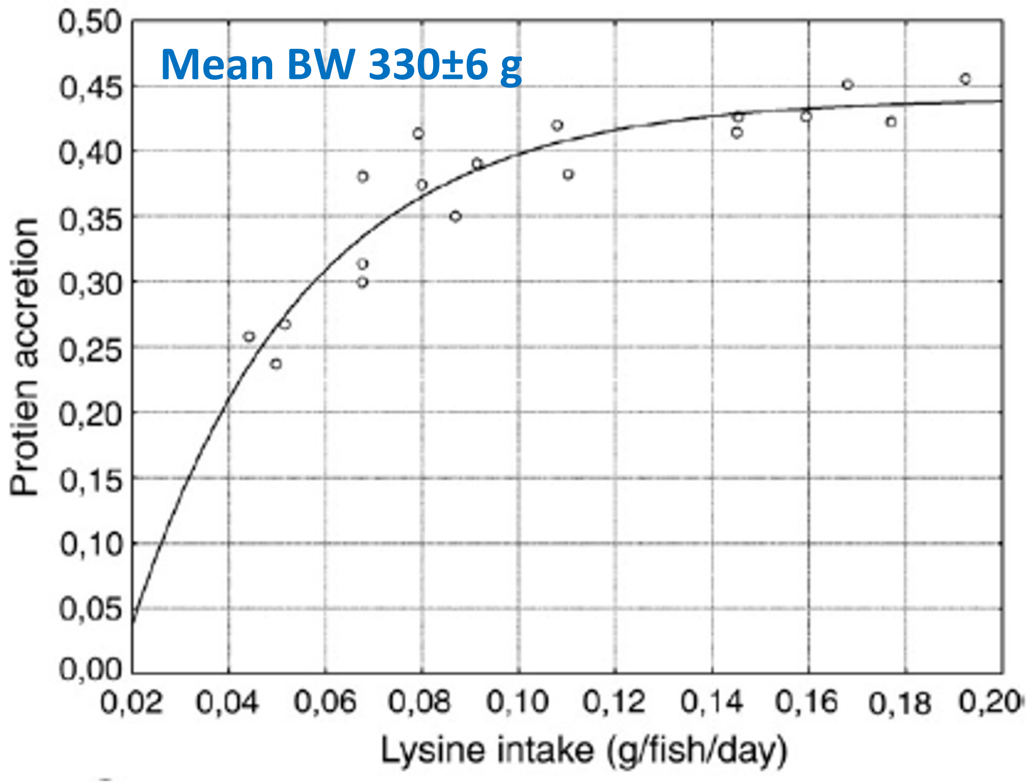
- Be willing to pay for improved animal health and disease resistance

Assessment of lysine requirement for maximal protein accretion in Atlantic salmon using plant protein diets

Marit Espe [a,*], Andreas Lemme [b], Alfred Petri [b], Adel El-Mowafi [c]

“Dietary Lys did not affect growth (p>0.05), but the protein accretion suggested an optimum dietary Lys supply of 5.04 g /16 g N (corresponding to 0.12 g Lys/fish/day).”





Actions to Improve Efficiencies

- Invest in multifactorial growth studies research
  - Wide range of fish weights (from juveniles to harvest weight)
  - Range of temperatures (repeat during different seasons)
  - Wide range of dietary protein to dietary energy ratios
- Barramundi
- Spiny Lobster
- King (Chinook) Salmon
- Tilapia
- Expensive and time consuming,
  but worth it

Barramundi

Growth Rate x Temperature x Live Weight

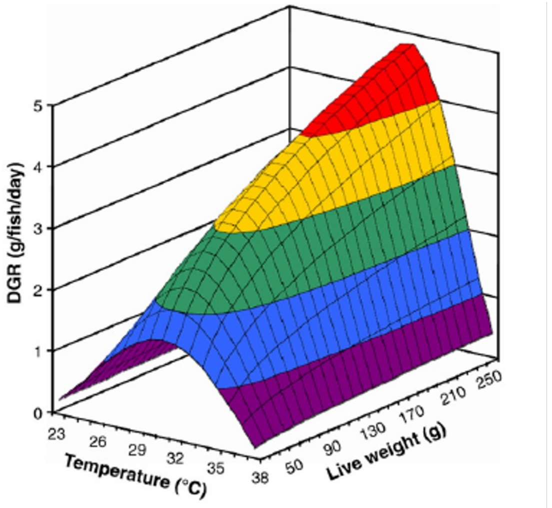


Fig. 1. Model of the daily growth rate (DGR) of juvenile (21–142 g) barramundi (*Lates calcarifer*) grown at temperatures ranging between 23.3 °C and 37.9 °C. The raw data was fitted with Eq. 1.

Bermudes et al. 2010

TARS 2022
The Aquaculture Roundtable Series

Actions to Improve Efficiencies

- Stop thinking about minimizing feed cost with cheap feeds
  - Least-cost feeds are a false economy
- Start thinking about maximizing feed efficiency instead
  - Quality costs money
  - You get what you pay for
  - Focus on maximum nutrient digestibility
    - Do *in vivo* digestiblity studies
  - Use feed enzymes to reduce the effects of phytic acid, fibre and oligosaccharides
  - Use protease enzymes to increase protein digestibility
- Realize that there is no benefit in buying high fibre ingredients and shipping them halfway around the world *at high cost*, just to decrease feed digestibility, increase FCRs, and pollute water in the farm
  - Fibre from outer surfaces of grains and seeds are often reservoirs of mycotoxins

AQUAFEEDS
A New Equilibrium

Actions to Improve Efficiencies

- Start finding ways to use the knowledge gained from 21st Century technologies
  - Molecular biology tools like gene expression
    - European study feeding graded levels of lysine to Atlantic salmon and tracking gene [+/-] expression (Hevrøy et al. 2007)
    - Alterations in expression of genes associated with muscle metabolism and growth (Johansen and Overturf 2006)
    - Diet energy composition affects muscle fiber recruitment, body composition and growth in Rainbow trout (Overturf et al. 2016)
  - Epigenetics
    - Early life nutritional programming (Moghadam et al. 2015)
    - Immune system priming (Menon et al. 2016, Terova et al. 2016)
  - Nutrigenomics
    - Use molecular probes to evaluate effects of nutrients on growth and health (Overturf and Hardy 2001, Overturf et al. 2004, Alami-Durante et al. 2010)

Thank you for your attention

References are provided in the PDF version of this presentation

References

- Alami-Durante, H., Wrutniak-Cabello, C., Kaushik, S.J. and Médale, F., 2010. Skeletal muscle cellularity and expression of myogenic regulatory factors and myosin heavy chains in rainbow trout (Oncorhynchus mykiss): effects of changes in dietary plant protein sources and amino acid profiles. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 156(4), pp.561-568.
- Bermudes, M., Glencross, B., Austen, K. and Hawkins, W., 2010. The effects of temperature and size on the growth, energy budget and waste outputs of barramundi (Lates calcarifer). *Aquaculture*, *306*(1-4), pp.160-166.
- Espe, M., Lemme, A., Petri, A. and El-Mowafi, A., 2007. Assessment of lysine requirement for maximal protein accretion in Atlantic salmon using plant protein diets. Aquaculture, 263(1-4), pp.168-178.
- FishStatJ, F.A.O., 2015. Fisheries and aquaculture software. FishStatJ-Software for Fishery Statistical Time Series. Rome: FAO Fisheries and Aquaculture Department.
- Hevrøy, E.M., El-Mowafi, A., Taylor, R.G., Olsvik, P.A., Norberg, B. and Espe, M., 2007. Lysine intake affects gene expression of anabolic hormones in Atlantic salmon, Salmo salar. General and comparative endocrinology, 152(1), pp.39-46.
- Johansen, K.A. and Overturf, K., 2006. Alterations in expression of genes associated with muscle metabolism and growth during nutritional restriction and refeeding in rainbow trout. Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology, 144(1), pp.119-127.

References

- Menon, P. and Kumar, M.S., 2016. Trans generational immune priming in aquaculture-disease combating potential. *International Journal of Fisheries and Aquatic Studies*, *4*, pp.126-130.
- National Research Council, 2011. Nutrient requirements of fish and shrimp. National academies press.
- O'Donncha, F. and Grant, J., 2019. Precision aquaculture. IEEE Internet of Things Magazine, 2(4), pp.26-30.
- Overturf, K. and Hardy, R.W., 2001. Myosin expression levels in trout muscle: a new method for monitoring specific growth rates for rainbow trout Oncorhynchus mykiss (Walbaum) on varied planes of nutrition. Aquaculture Research, 32(4), pp.315-322.
- Overturf, K., Bullock, D., LaPatra, S. and Hardy, R., 2004. Genetic selection and molecular analysis of domesticated rainbow trout for enhanced growth on alternative diet sources. Environmental biology of fishes, 69(1), pp.409-418.
- Penberthy, W.T. and Kirkland, J.B., 2020. Niacin. In Present Knowledge in Nutrition 11th Edition (pp. 209-224). Academic Press.
- Terova, G., Díaz, N., Rimoldi, S., Ceccotti, C., Gliozheni, E. and Piferrer, F., 2016. Effects of sodium butyrate treatment on histone modifications and the expression of genes related to epigenetic regulatory mechanisms and immune response in European sea bass (Dicentrarchus labrax) fed a plant-based diet. PLoS One, 11(7), p.e0160332.
- Zhang, Y., Lu, R., Qin, C. and Nie, G., 2020. Precision nutritional regulation and aquaculture. Aquaculture Reports, 18, p.100496.