Feeding Practice for Improved Productivity and Reduced Environmental Impacts

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Key Steps to Improving Efficiency and Reducing Environmental Impacts of Aquaculture

1) Adequately assessing the productivity, waste outputs and the environmental impacts of aquaculture operations

2) Improving feed efficiency and minimizing the release of wastes through improvement in feed quality

3) Improving production efficiency and minimizing or managing the release of wastes through improvement of farm production processes (e.g. production and feeding management)

1. Adequately characterizing productivity, waste outputs and environmental impacts of aquaculture operations

"You can't manage what you can't measure."

Peter Druker

Towards Effective Performance Benchmarking of Ontario Rainbow Trout Farms

Owen Skipper-Horton, Dominique P. Bureau
University of Guelph

Survey Summary

- **5 commercial sites, 1 experimental (Experimental Lakes Area, ELA)**
- **Commercial sites: Sep 2008 to Jun 2012**
- **ELA: 2003-2007**
- **128 total commercial production lots (cages)**

Freshwater Cage RBT Culture in Ontario, Canada

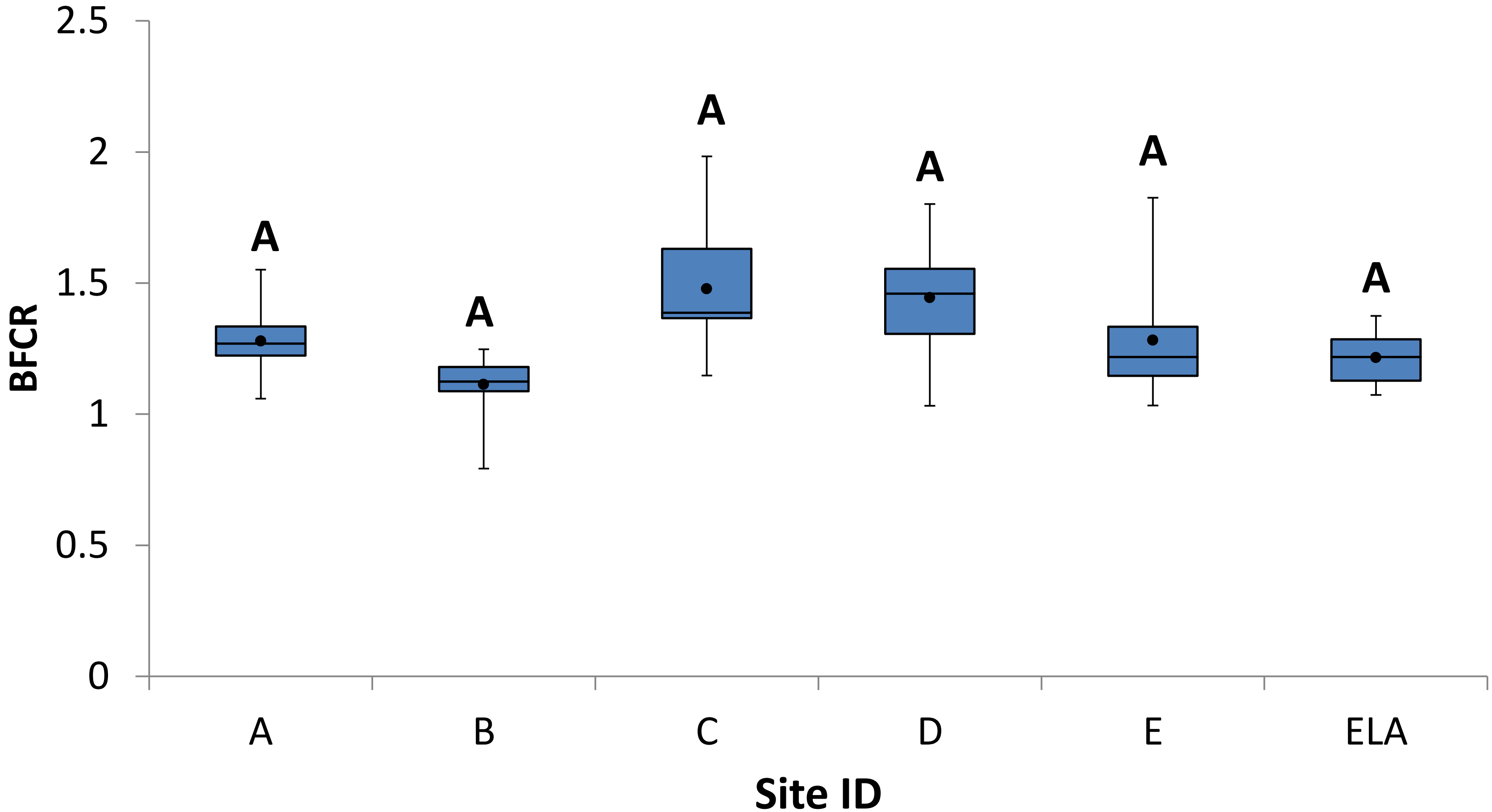
- Open-water cage production of rainbow trout
- Average grow-out period (10 g to 1 kg BW) = 16 months (long and risky!)

Autumn

Winter

Biological Feed Conversion Ratio (BFCR*)

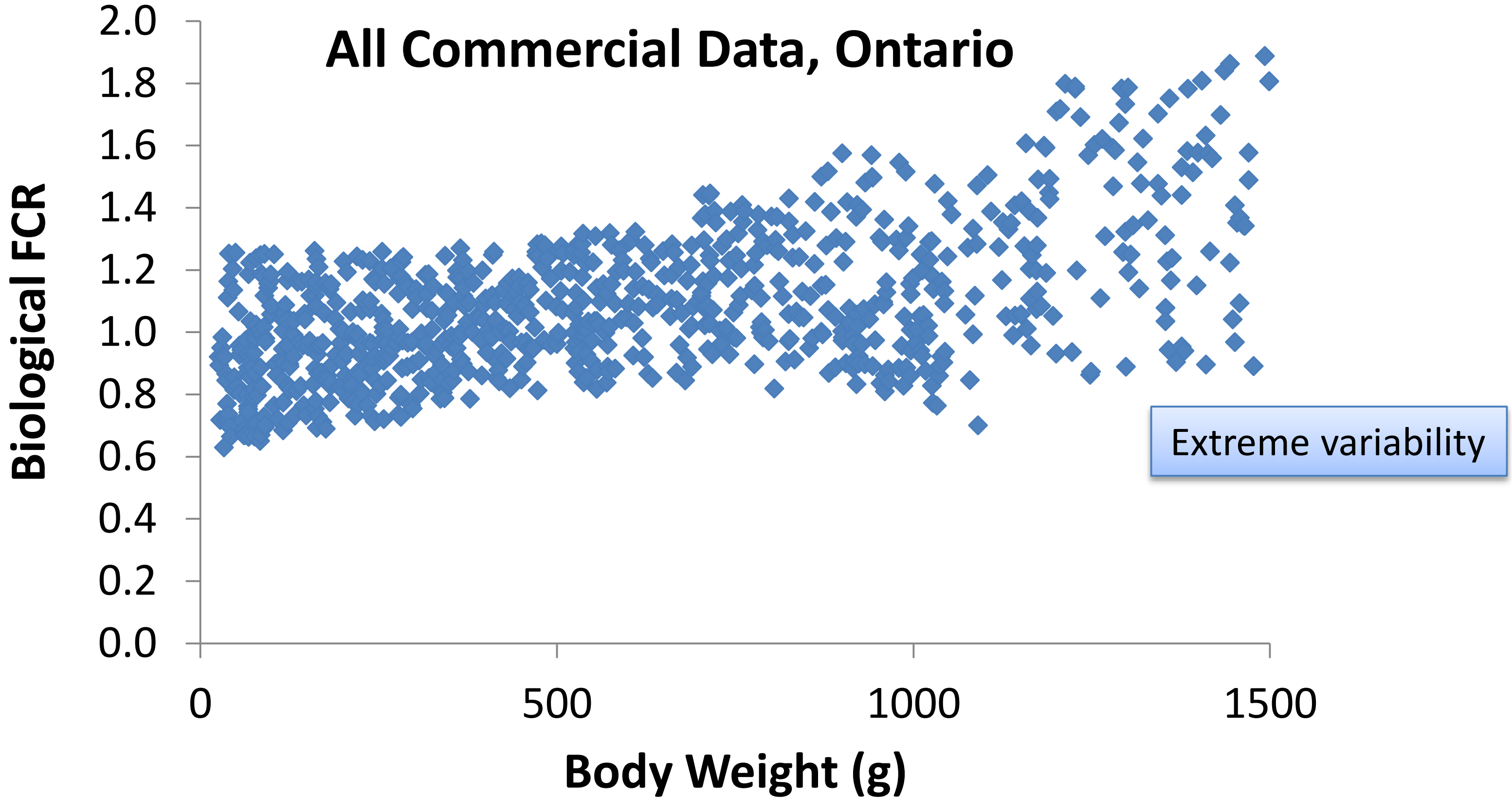
BFCR = feed served *per fish* : avg weight gain *per fish



Different farms / lots use feed resources with different efficiencies and thus produce different of wastes.

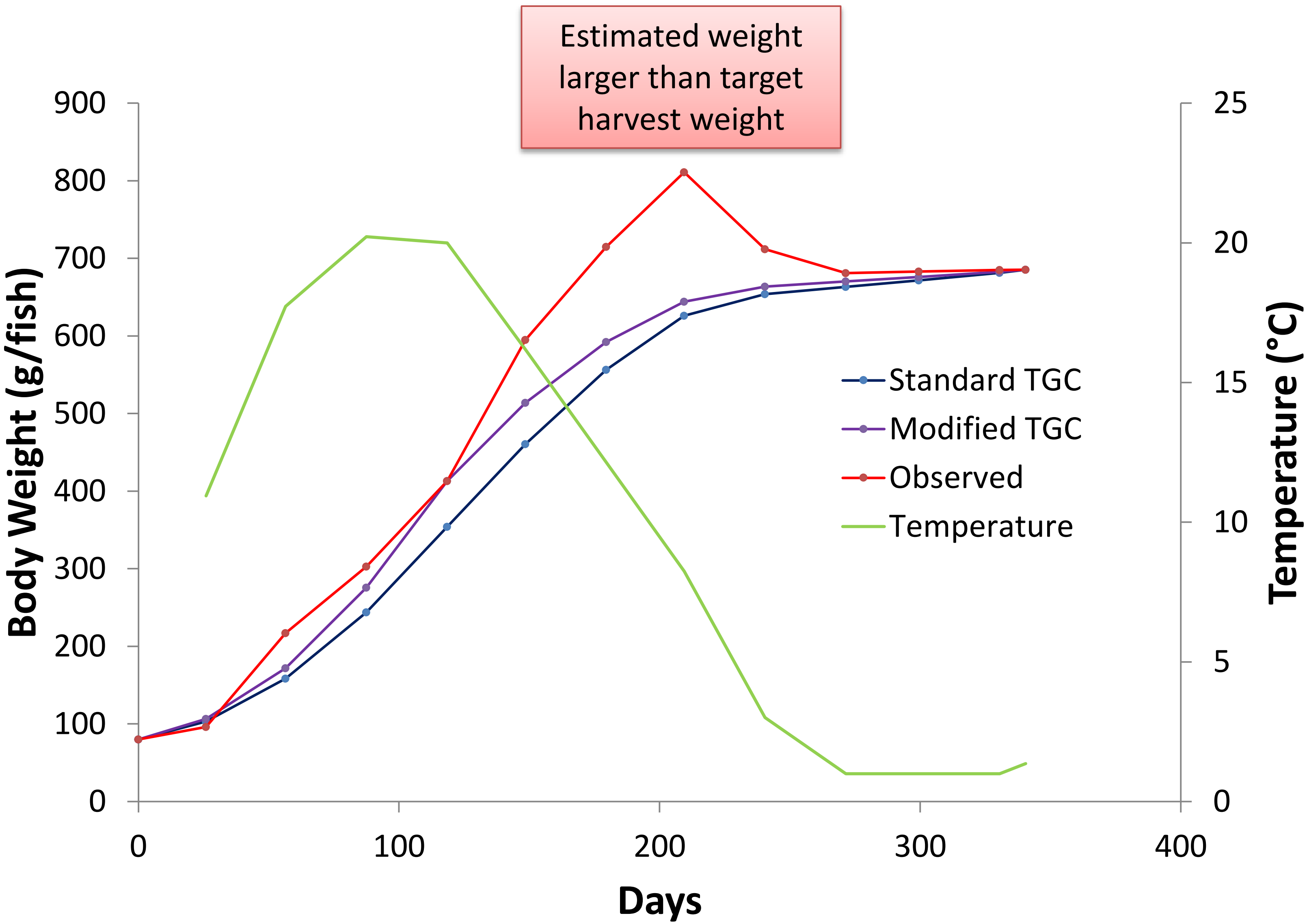
– Results –

FCR vs. BW



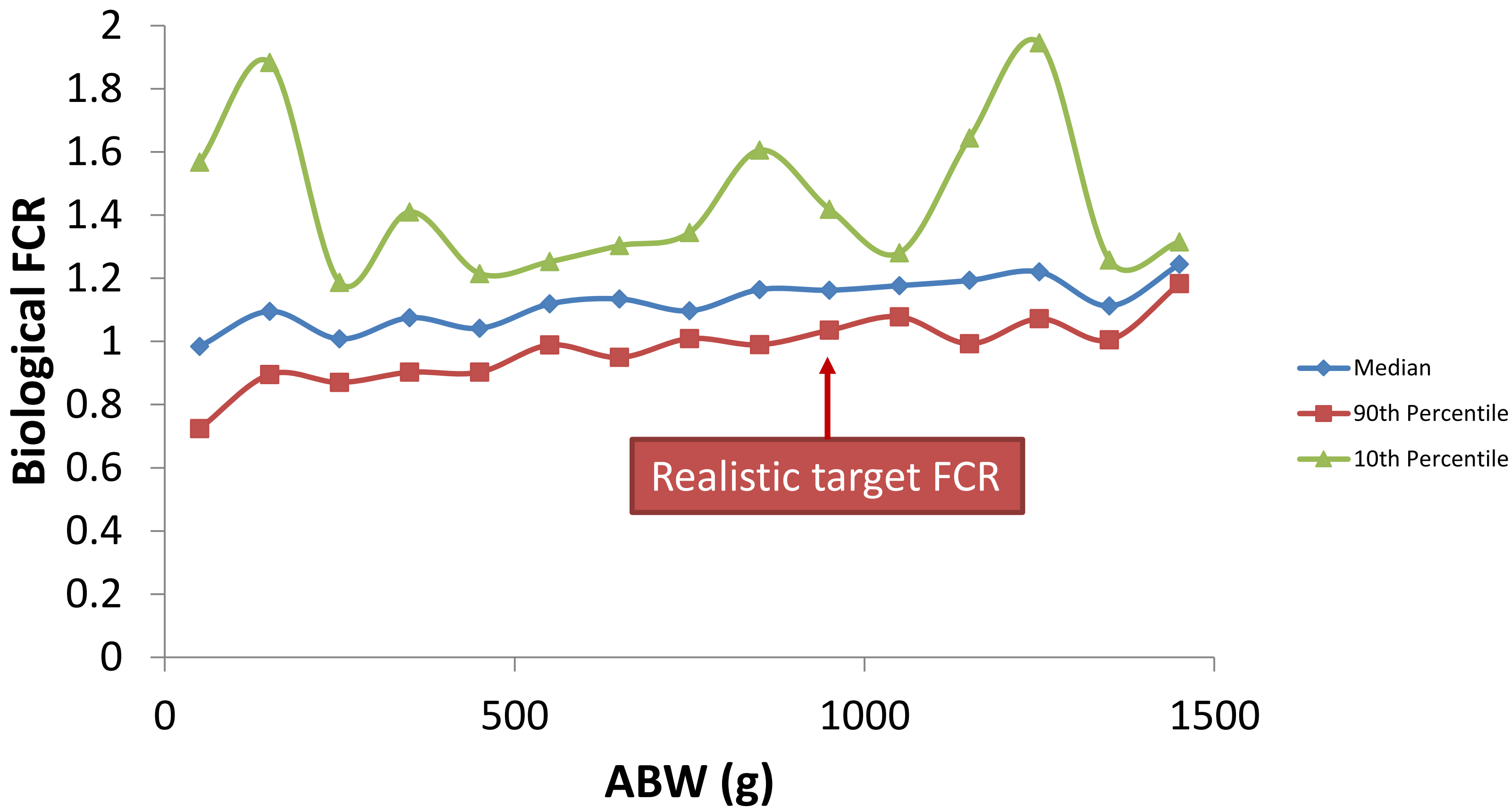
- Extreme variability of field data.
  - Origin: Biological/environmental variability or sampling errors?
- Data suggests increase in feed conversion ratio as fish weight increases as suggested by models

Growth Trajectory of Rainbow Trout on a Cage Culture Operation



The Power of Advanced Analysis of Real Production Data

Ex: FCR vs. Average Body Weight (ABW)



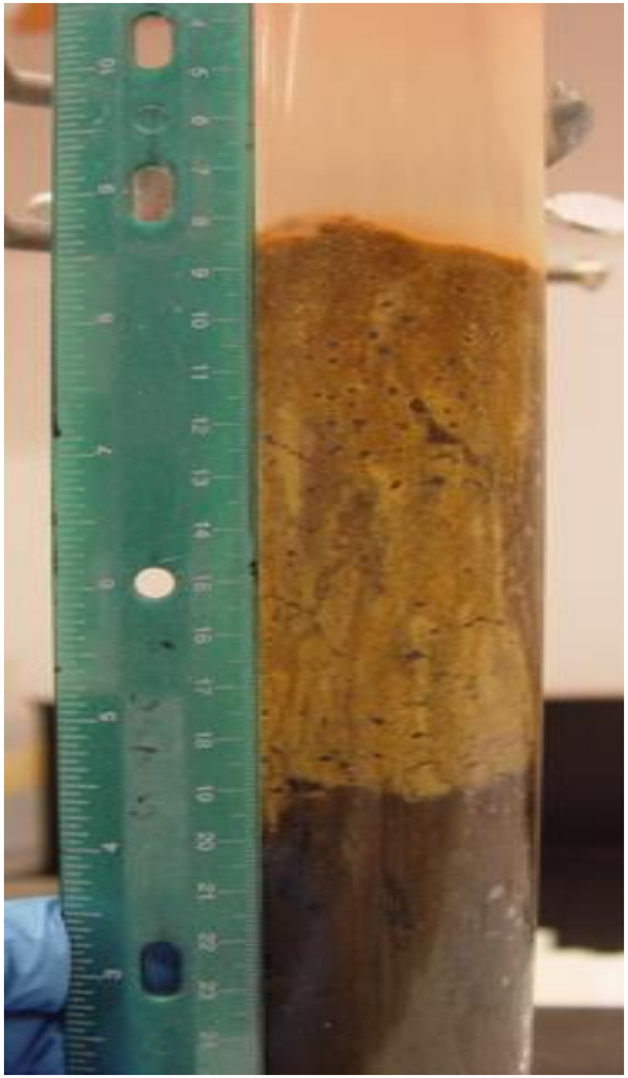
- Advanced statistical analysis of the data provide novel way of looking at highly variable field data and identifying achievable "targets" (as opposed to "ad hoc" ones)

- Auditing/cleaning of field data against model simulation and combining or contrasting theoretical feed requirement model simulation and realistic targets could prove very powerful

Different types of wastes are of concern depending on type of aquaculture operation

- For freshwater fish culture operations:
  - Solid wastes (especially solid organic wastes)
  - Phosphorus wastes (especially dissolved P wastes)

- For marine fish culture operations:
  - Solid wastes (especially organic wastes)
  - Nitrogenous wastes (especially dissolved N wastes)



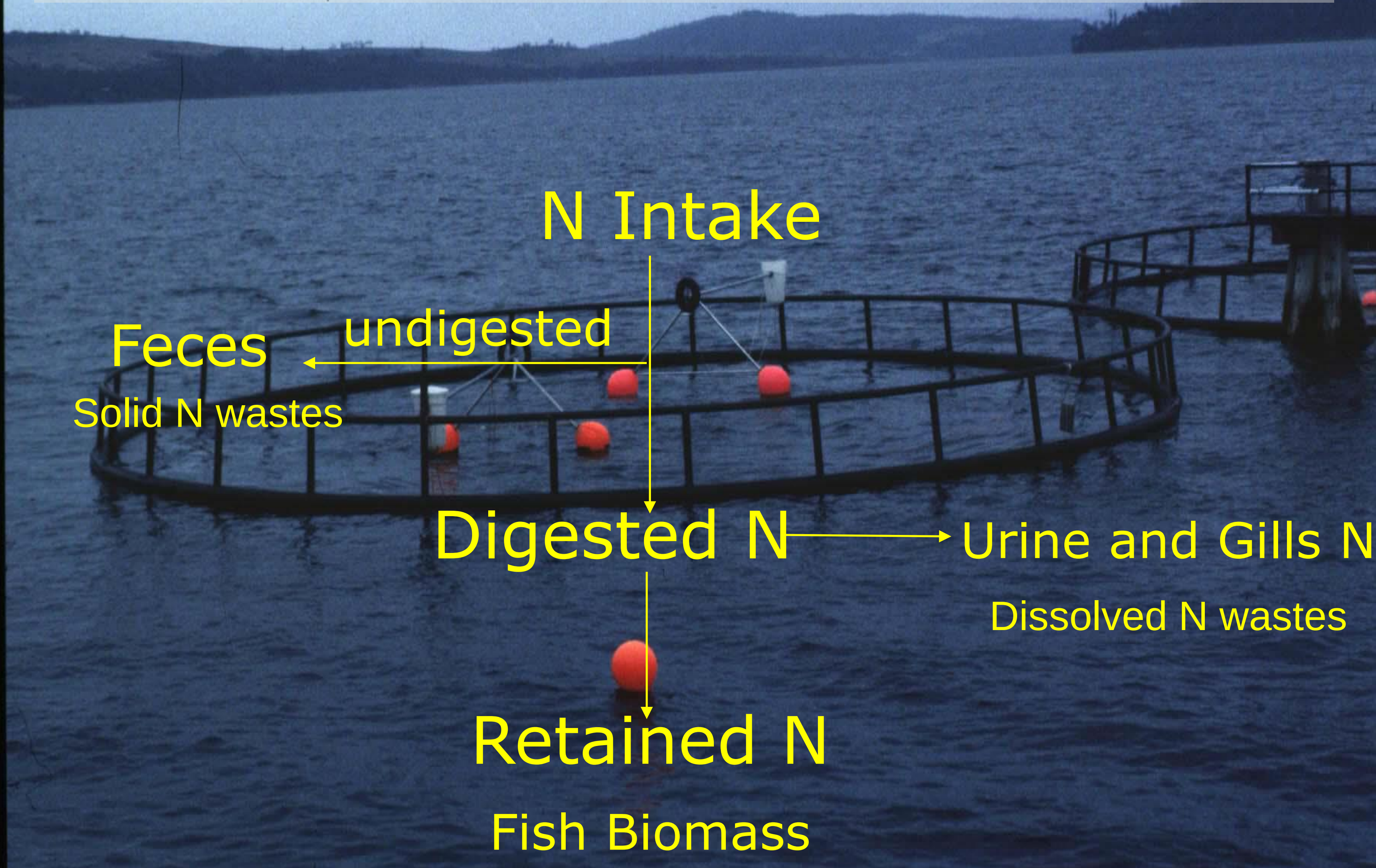
Solid Wastes

Phosphorus Wastes

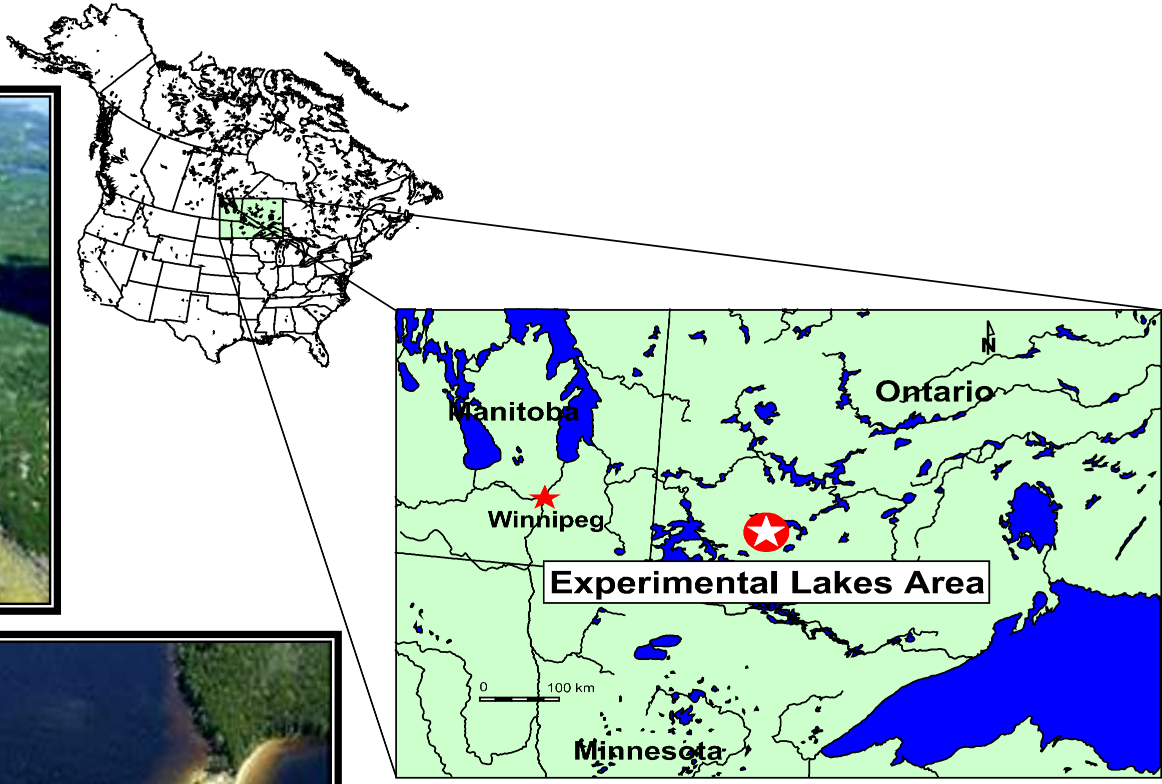
- Phosphorus (orthophosphate) is of major concern in freshwater because it is the most limiting factor for algal growth and eutrophication

Effect of P was demonstrated in series of studies conducted between 1968-1975 at Experimental Lakes Area (ELA) by Dr. David Schindler & collaborators from Freshwater Institute (Winnipeg, Manitoba)

Estimating Waste Output - Nutritional Approach



The Experimental Lakes Area



58 lakes (1 to 84 ha)
monitored for past 30 years

Freshwater Institute Science Laboratory

Five production cycles – 2003-2007
Limnological & ecological assessments
Whole project: > 30 scientists and students

UG/OMNR Fish Nutrition Research Lab (U of Guelph)

Feed and fish composition analysis
> 140 samples
Digestibility trials -2004, 2006, 2007
Fish-PrFEQ Model development

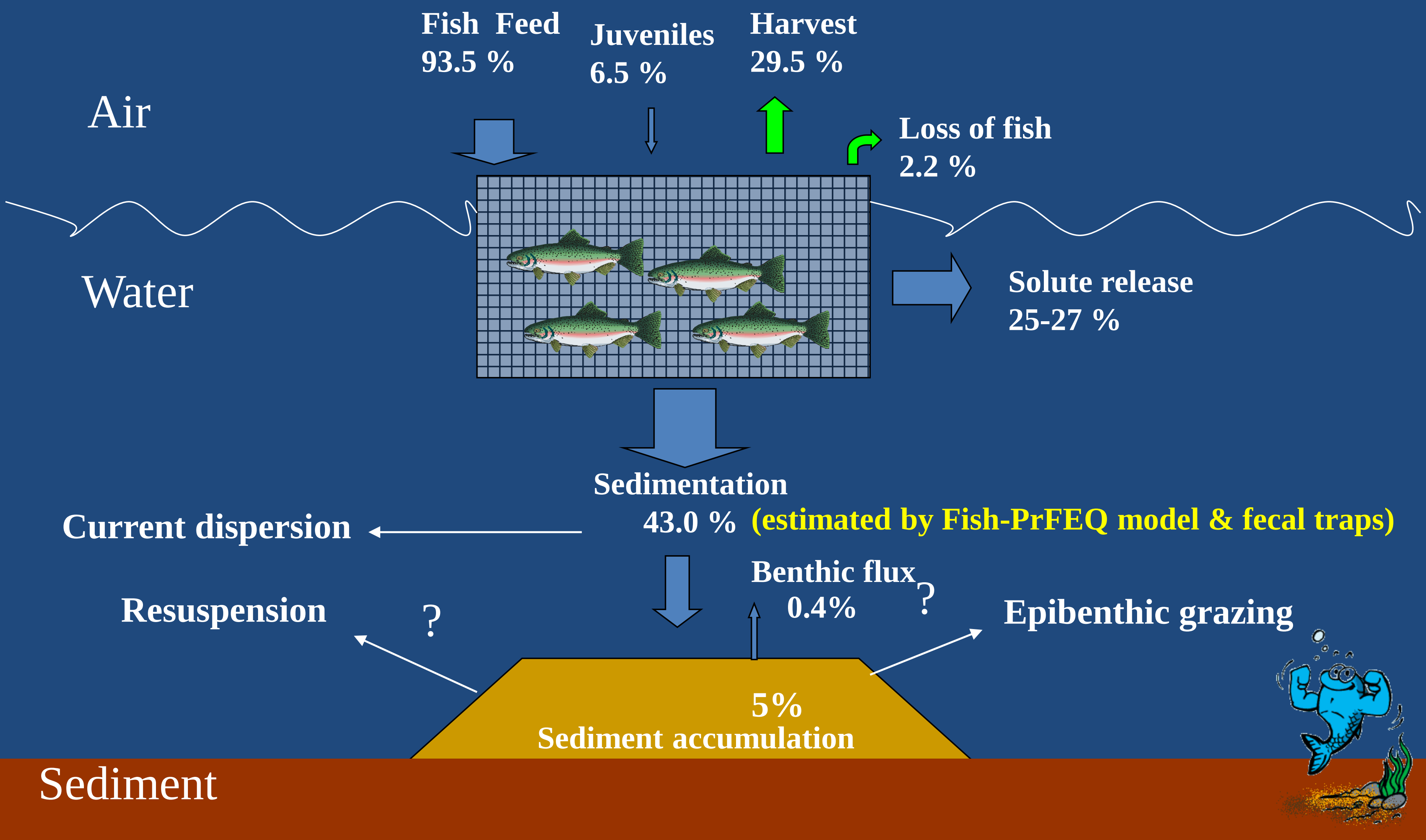
“Extreme Science” Team of Experimental Lake Area (ELA)

Growth Performance

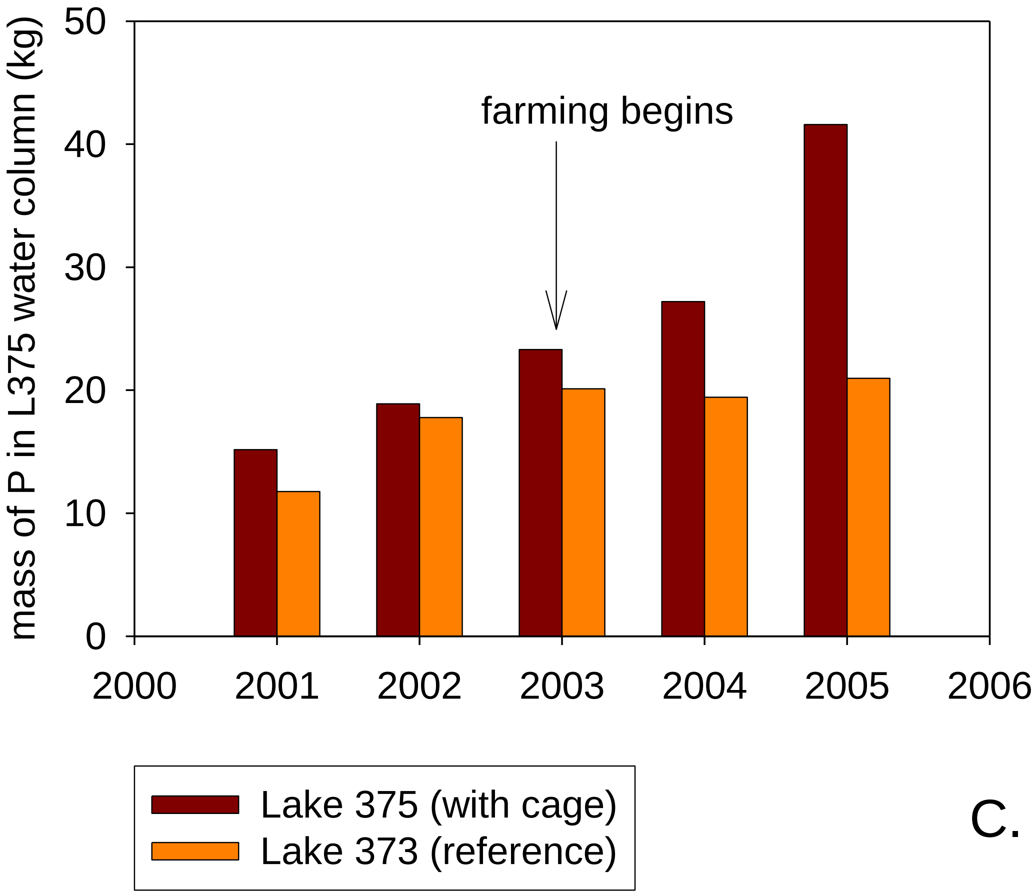
Parameter	2003	2004	2005	2006	2007
Trial duration (d)	167	155	153	162	176
Average temp. (ºC)	15.1	14.3	14.6	16.2	15.3
IBW (g/fish)	94.0	101.3	189.9	61.3	69.0
Gain (g/fish)	756.0	894.9	919.8	747.1	871.5
TGC	0.195	0.242	0.204	0.206	0.213
Feed Intake (g/fish)	854.6	972.5	1182.9	997.8	1260
FCR (feed/ gain)	1.13	1.09	1.29	1.34	1.45

TGC = thermal-unit growth coefficient = $(FBW^{1/3} - IBW^{1/3})/\Sigma\ (T * days)$, (Iwama and Tautz,1981)

Phosphorus mass balance for 2005



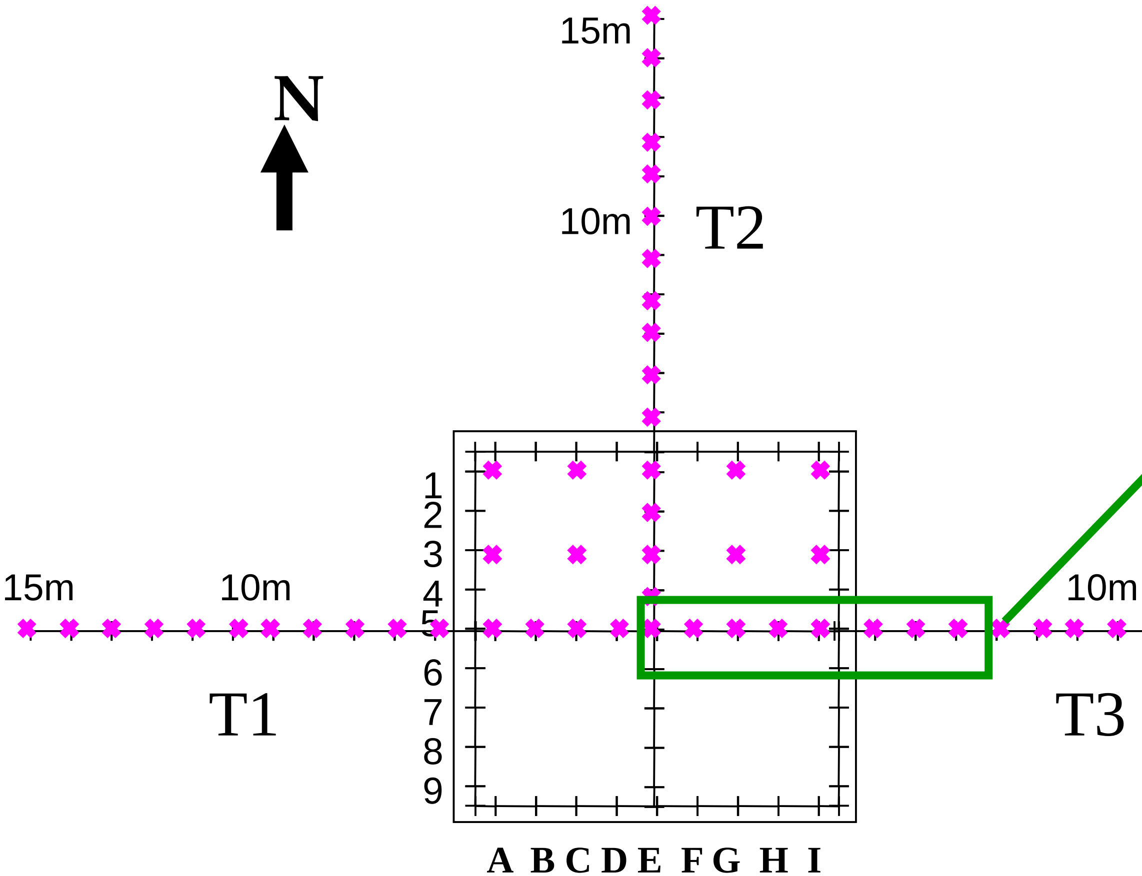
Azevedo and Podemski (2007)

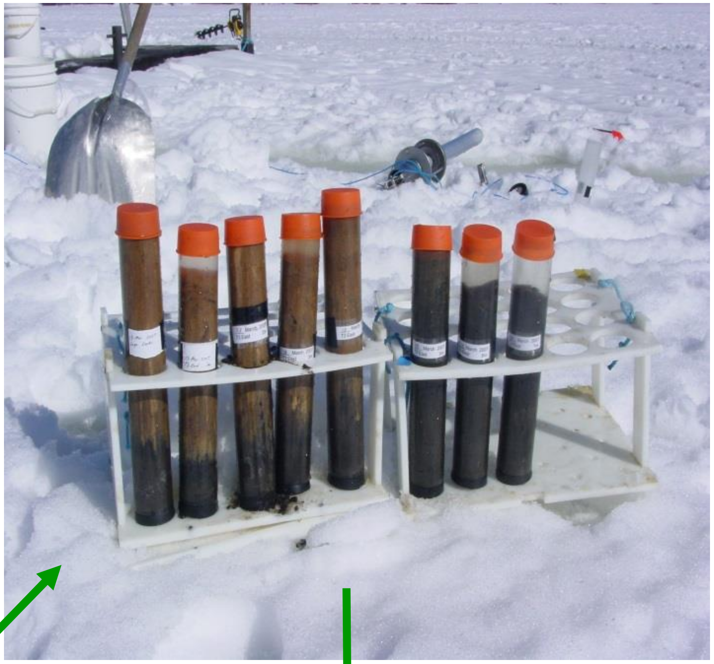


C. Bristow & R. Hesslein

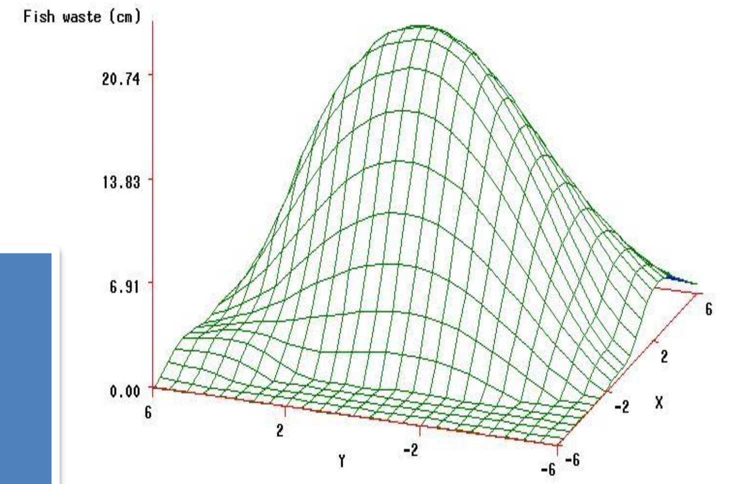
The mass of P in water column increased an average of 8.6 kg/year
An average of 64.5 kg P/year was added by the cage operation
Only 15% of the P added to L375 remained in the water column

Mapping Solid Waste Accumulation





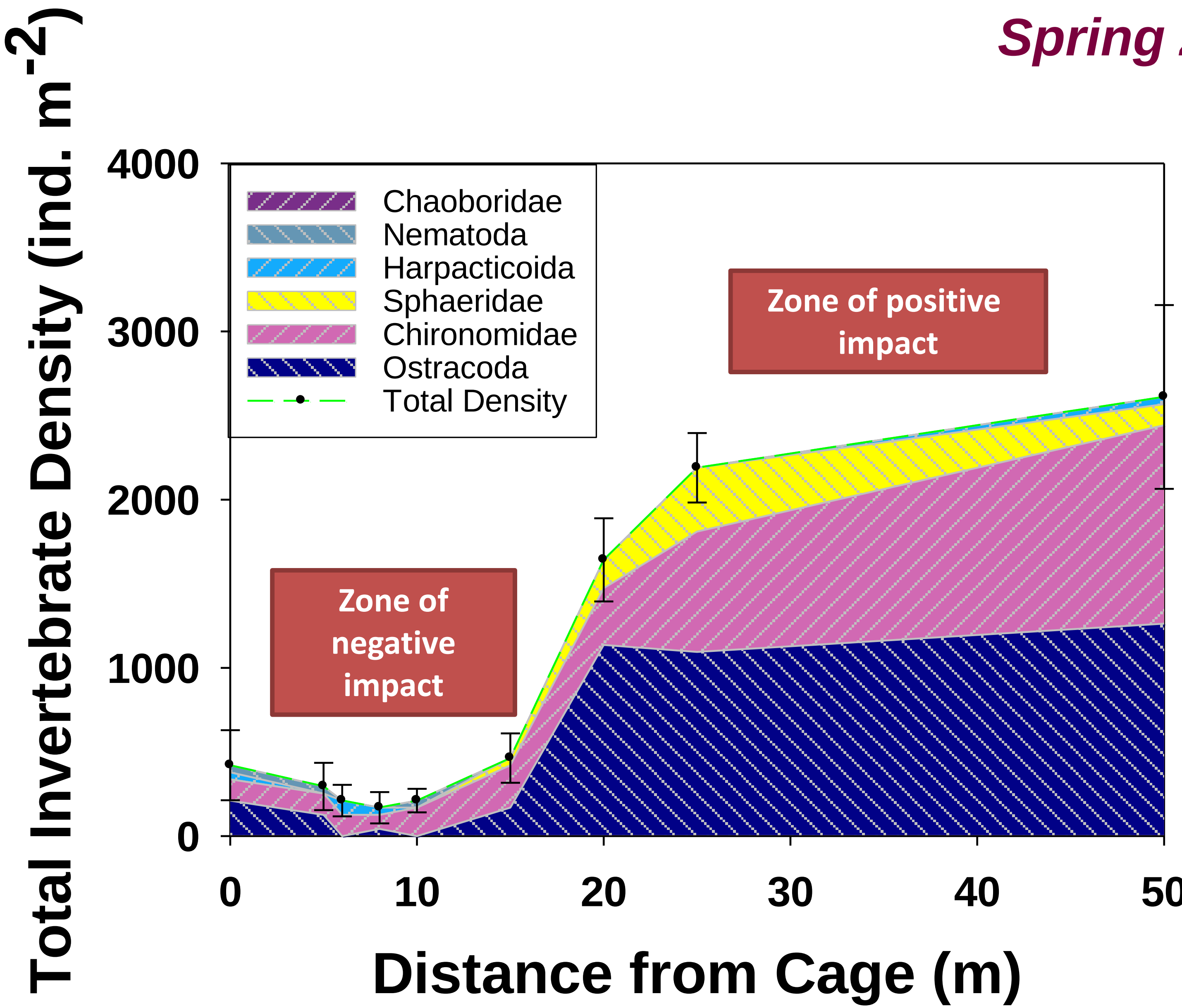
Surface plot of Fish Waste Depth after smoothed spline interpolation



10 x 10 M cages = 16 x 16 M footprint
where accumulation of solid wastes is significant

Volume = 17 M^3

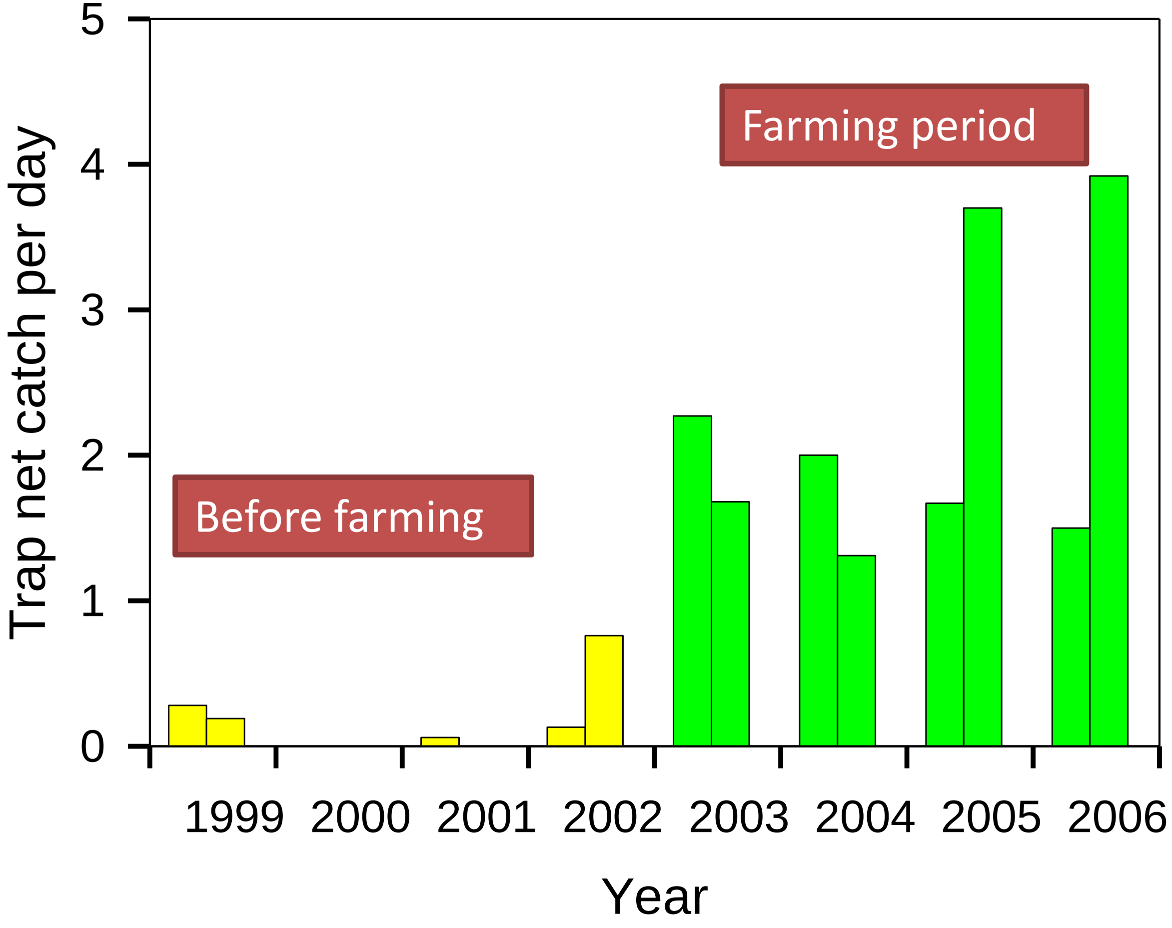
Spring 2005



R. Rooney & C. Podemski

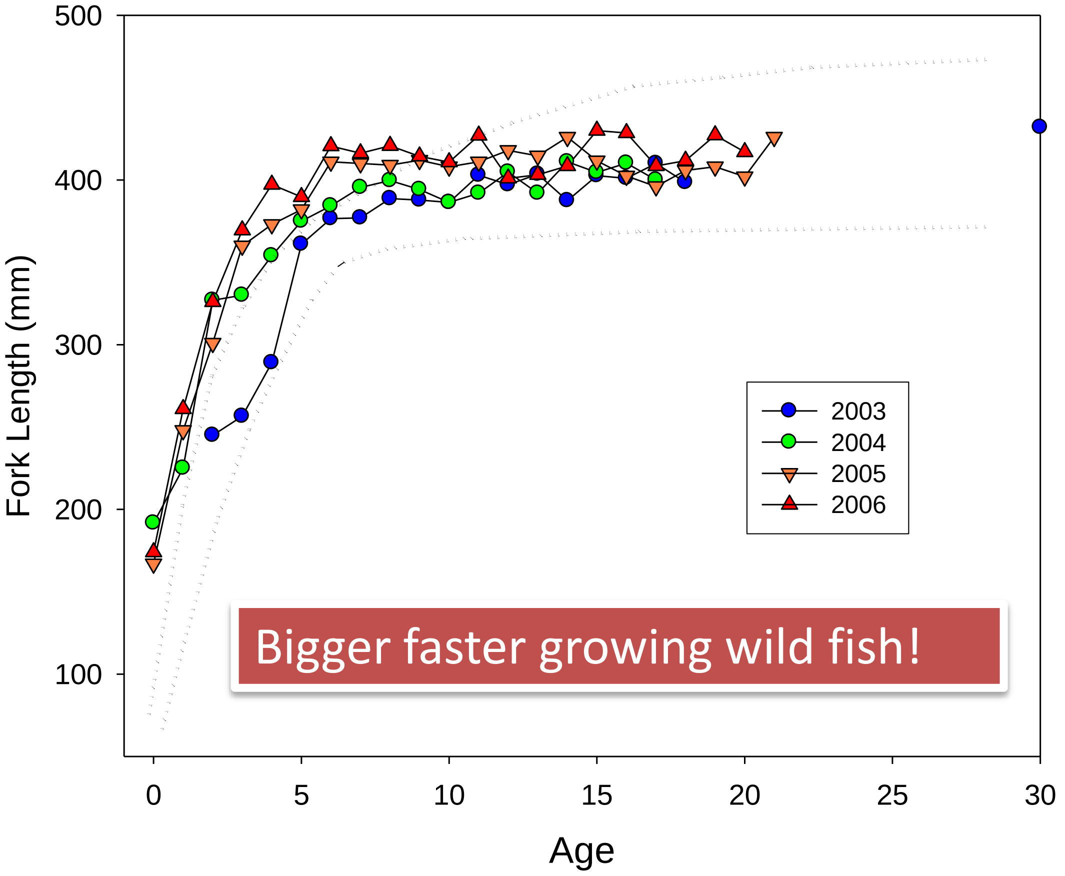
Lake 375

Slimy sculpin (forage fish)



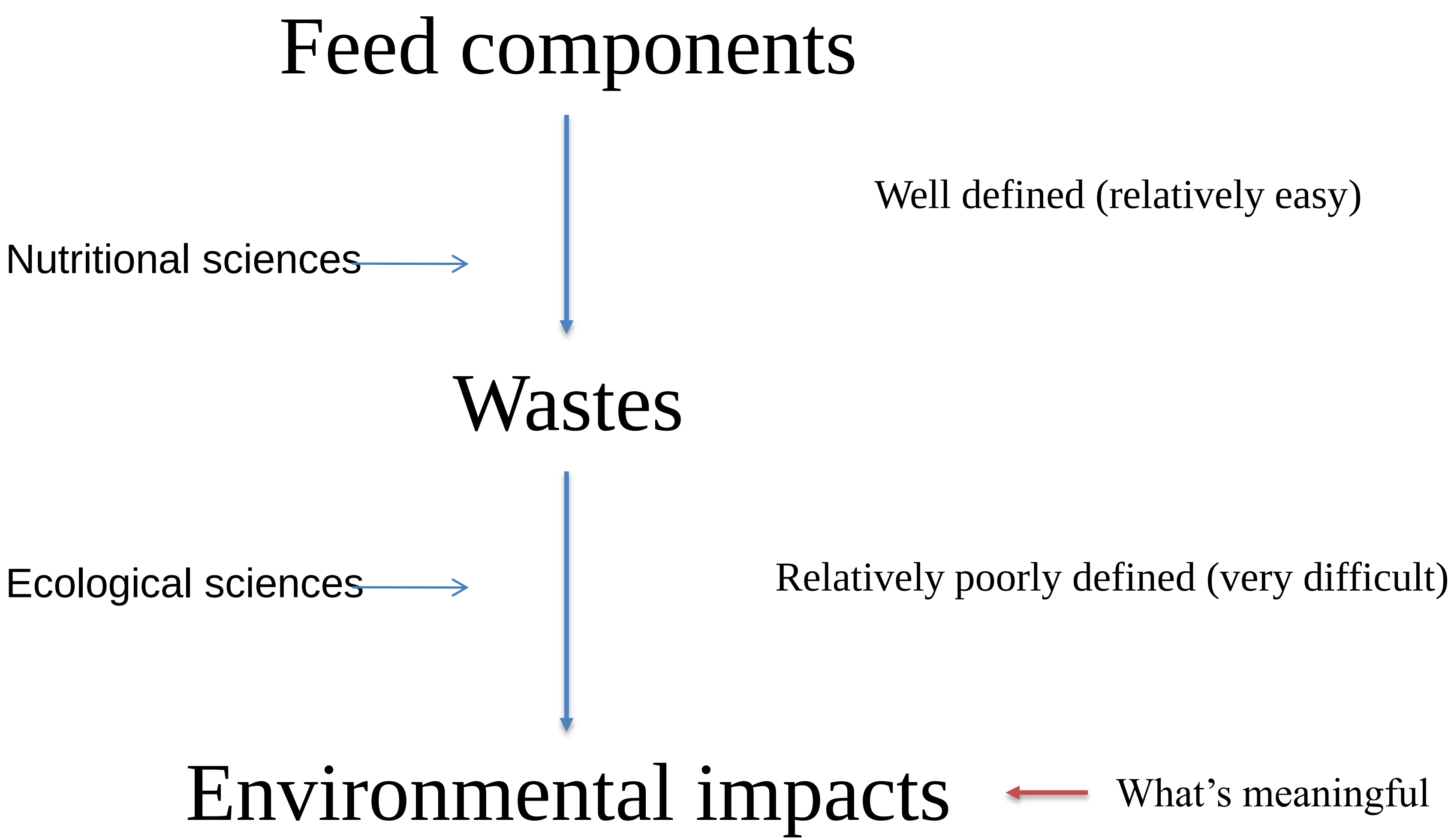
Ken Mills and Sandy Chalanchuk

Growth: Lake 375 lake trout



Ken Mills and Sandy Chalanchuk

Nutritional Management of Environmental Impacts?



2. Improving production efficiency and minimizing the release of wastes through improvement in feed quality

"The proof of the pudding is in the eating"

Old English Proverb

Estimation of Solid Waste Outputs of Rainbow Trout Fed Different Feeds

Parameters	1980's Feed	1990's Feed	2000's Feed
Digestible Protein, %	38	41	43
Digestible Energy, MJ/kg	17	19	20
Theoretical FCR[1], feed:gain	1.27	1.14	1.10
Total Solid Waste[2], kg			
per kg feed fed	0.22	0.20	0.15
per kg fish produced[1]	0.28	0.23	0.17

1 Based on estimated energy requirement of 21.5 MJ/kg weight gain for fish growing from 10 to 1,000 g

2 Based on published apparent digestibility coefficient of dry matter for common feed ingredients

Parameters	1980's Feed	2000's Feed	Progress achieved
Chemical Composition			
Crude Protein, %	36	44	Digestible nutrient density greatly increased
Lipid (Fat), %	10	24	
Digestible Energy, MJ/kg	14	19	
Phosphorus (P), %	2.5	1.1	
Apparent Digestibility Coefficient (%)[1]			
Dry matter (DM)	65	78	
Crude protein (CP)	85	88	
Gross energy (GE)	70	80	
Phosphorus (P)	50	60	
Theoretical FCR[2] , feed:gain	1.5	1.1	
Total Solid Wastes			
kg / tonne of feed fed	350	220	Reduced to less than half
kg / tonne of fish produced	540	250	
Solid Nitrogen Wastes			
kg / tonne fish produced	13	9	
Solid Phosphorus Wastes			
kg / tonne fish produced	19	5	Reduced to a fourth
Dissolved Nitrogen Wastes			
kg / tonne fish produced	48	43	
Dissolved Phosphorus Wastes			
kg / tonne fish produced	16	4	Reduced to a fourth

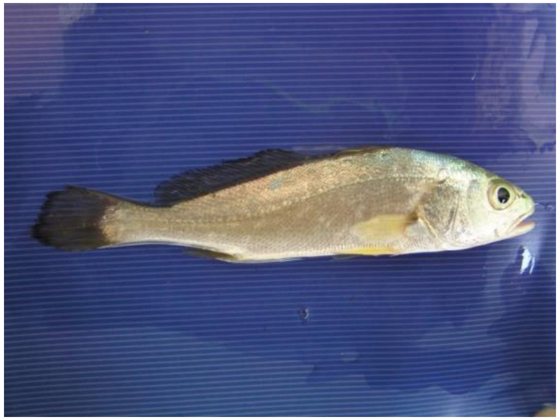
Marine Fish Cage Farm on Nanao Island, Guangdong, China

Field Experiments (2002-2005?)

Trash fish
(what farmers were using)

Total N wastes/t of fish produced

Cuneate drum



91 kg

Lab-made extruded dry feed
Formulated to different protein to digestible energy levels

45 kg

1) Feed Formulation Strategies

Key Issues :

Specifications for Multitude of Species and Life Stages

Specification for Different Production Systems / Markets

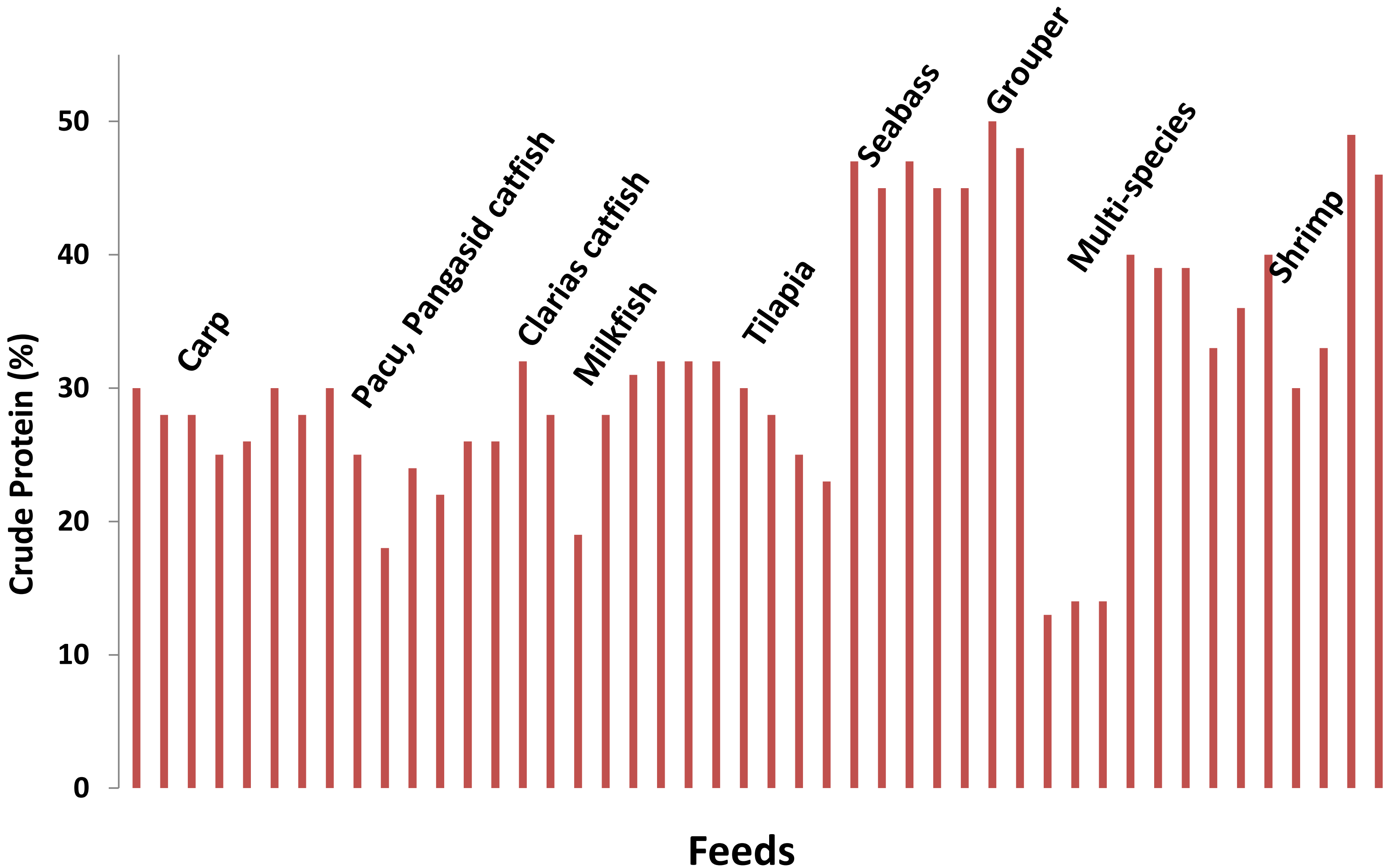
Waste Outputs and Potential Environmental Impacts

Suggested Strategies:

Optimize digestible nutrient specs for species and life stages

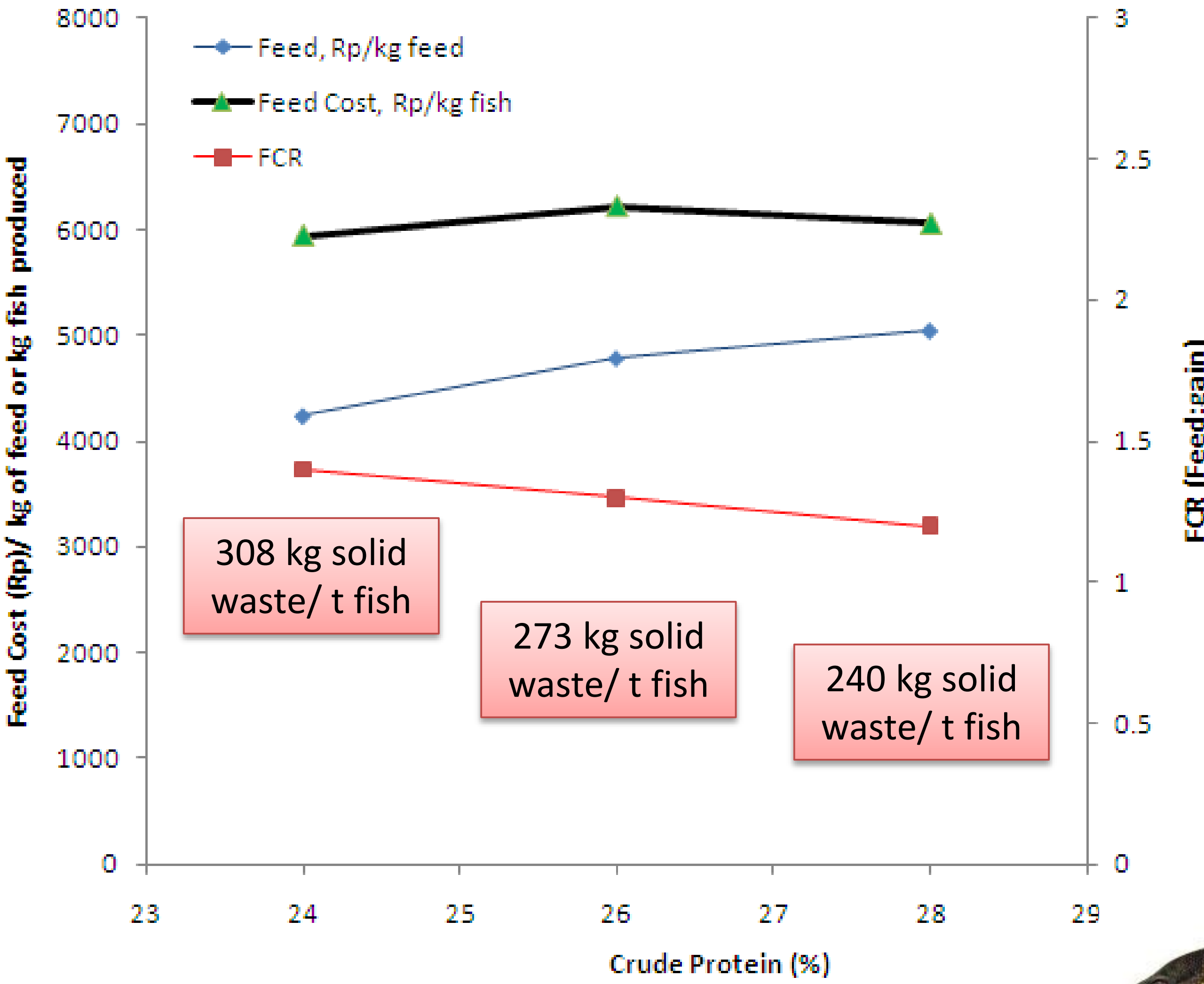
Optimize composition / nutrient density as a function of production and environmental constraints

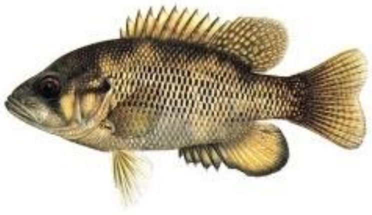
Protein Levels of Aquaculture Feeds Produced by a "Generalist" Aquaculture Feed Manufacturer



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

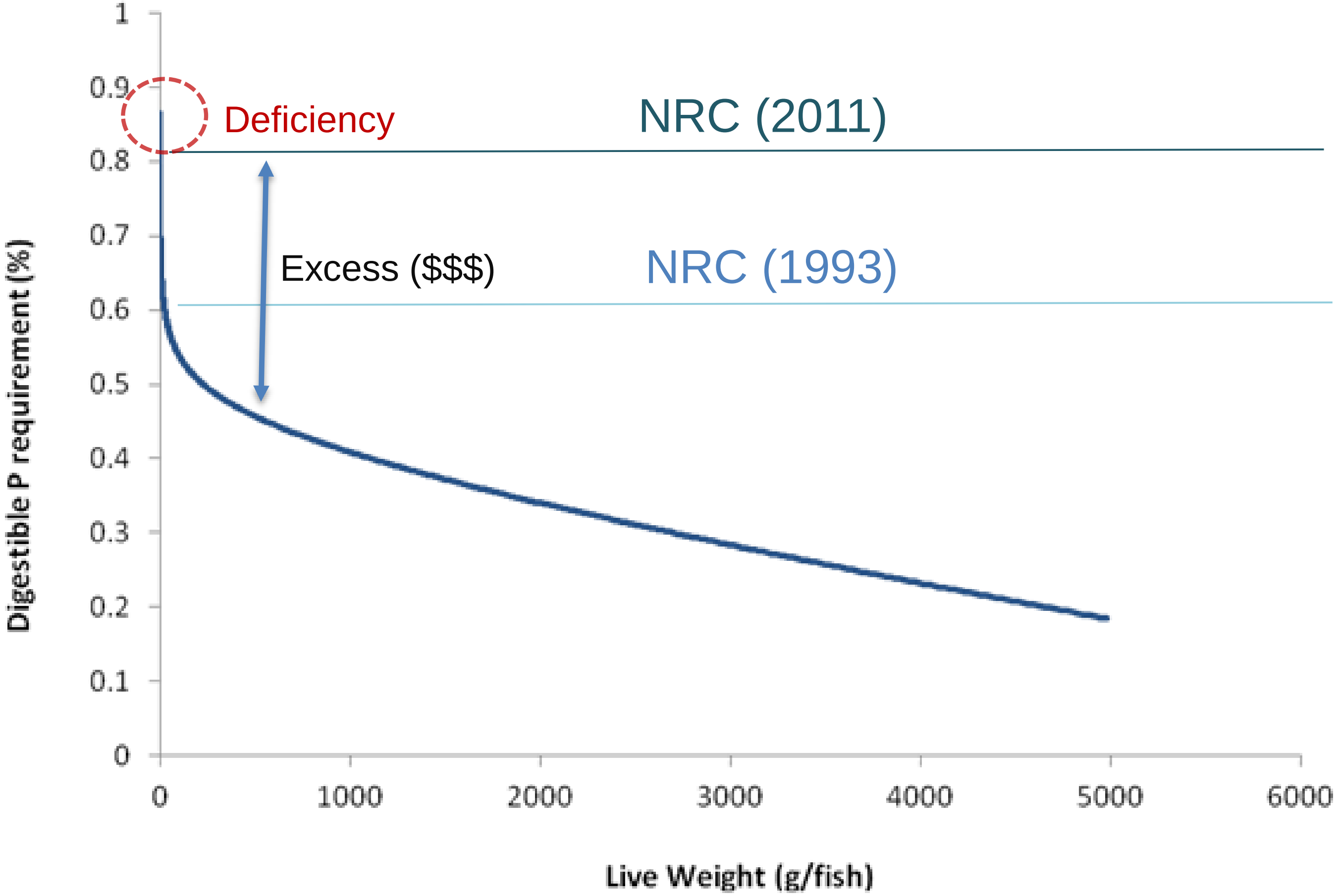
Feed Cost (Rp per kg of feed or kg of fish produced) and feed conversion ratio of Nile tilapia fed commercial feeds with different nutrient densities





Parameters		Commercial feed	Eco feed
Chemical composition			
Crude protein	%	33	33
Crude lipid	%	6.0	6.5
Phosphorus (P)	%	1.2	0.9
Digestible protein	%	28	29
Digestible energy	%	11	12
Fish produced and feed conversion			
Economical FCR	feed:gain	1.7	1.4
Fish production	tonne/year	2400	2400
Feed intake	tonne/year	4080	3360
Waste output			
Solid N waste	tonne/year	33	22
Dissolved N waste	tonne/year	118	91
Total N waste	tonne/year	150	112
Solid P waste	tonne/year	16	10
Dissolved P waste	tonne/year	16	3
Total P waste	tonne/year	32	13

Theoretical 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).

2) Ingredient-Related Strategies

Key Issues :

Chemical / Nutritional Composition

Digestibility and Bio-Availability of Nutrients

Presence of Anti-Nutritional Factors and Non-Nutrients

Suggested Strategies:

Characterization of Ingredient Quality

Judicious use of feed additive and processing techniques

Crude protein (CP), total dietary fiber (TDF) and coefficient of variation (CV) of TDF of various practical feed ingredients

Ingredients	CP	TDF	CV
	%	%	%
Soybean hulls	11	78	2
Cottonseed meal	28	60	6
Wheat bran	17	42	3
Corn gluten feed	21	38	50
Canola meal	35	28	19
Soybean meal	48	21	26
Corn	8	10	17
Corn gluten meal	60	6	8

Diet	Description
1	Diet with 0% soybean meal
2	Diet with 10% soybean meal
3	Diet with 20% soybean meal
4	Diet 1 supplemented with 1 g Superzyme CS/kg
5	Diet 2 supplemented with 1 g Superzyme CS/kg
6	Diet 3 supplemented with 1 g Superzyme CS/kg
7	Diet 2 supplemented with 2.5 g Superzyme CS/kg
8	Diet 3 supplemented with 2.5 g Superzyme CS/kg

Fecal Cohesiveness/Stability

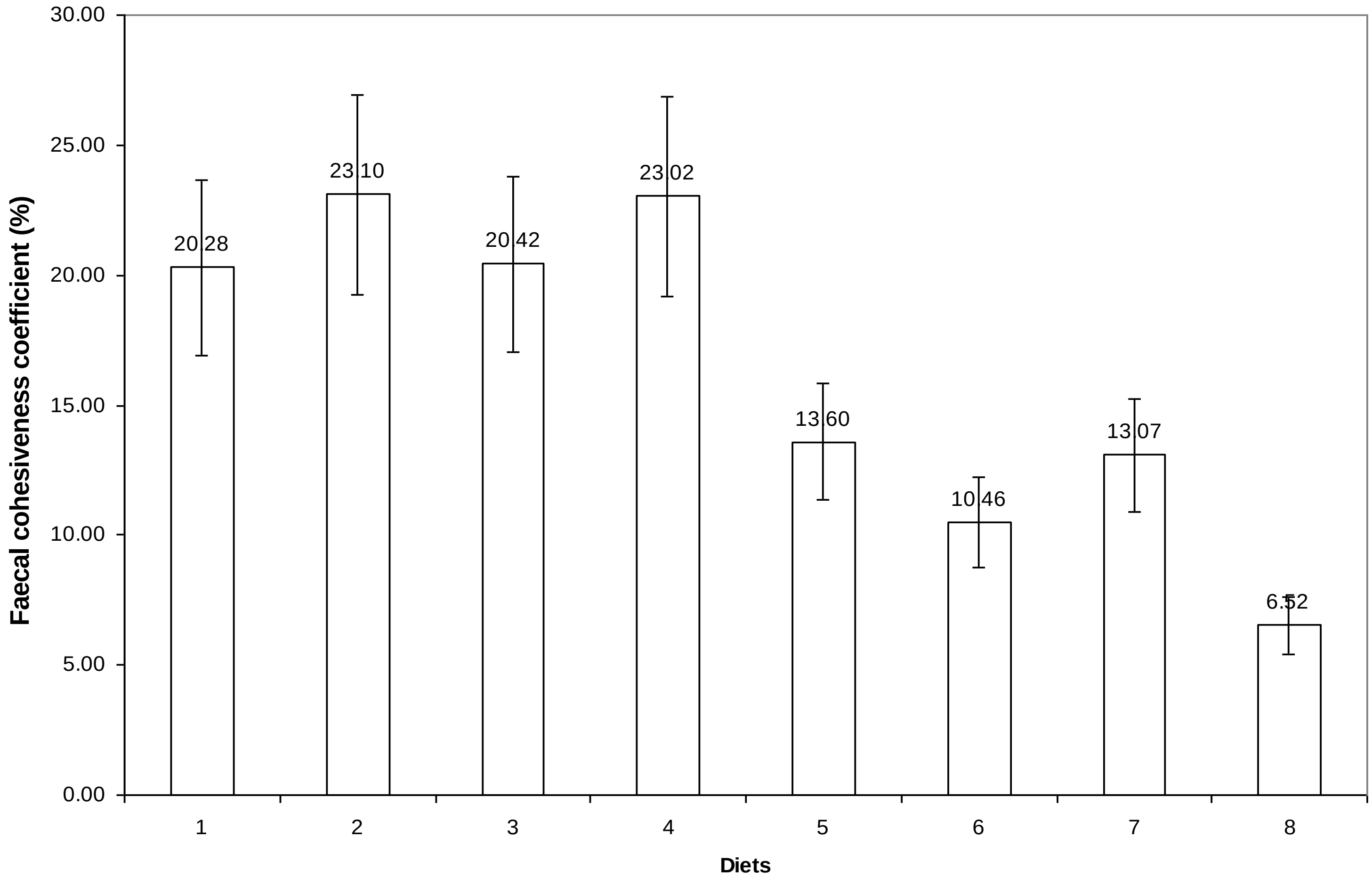


Figure 1: Faecal cohesiveness coefficient of faecal output from fish fed eight experimental diets over 6 weeks.

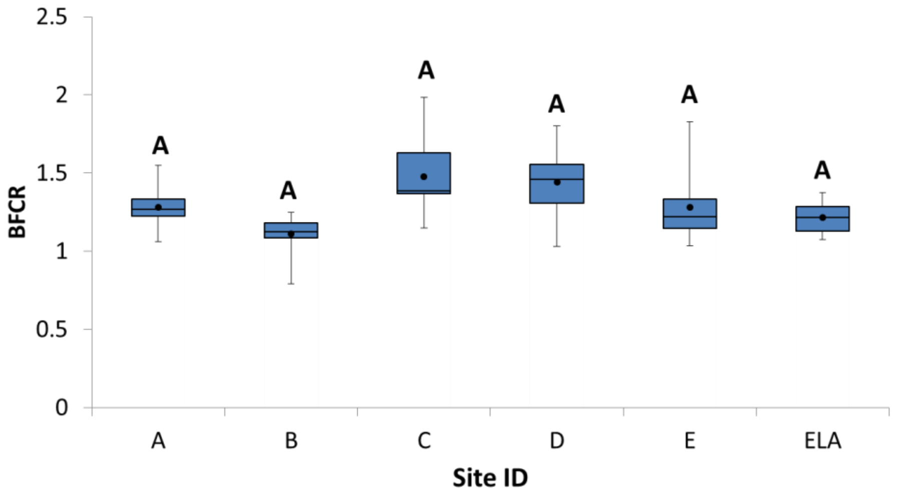
Feeds with Soybean Meal + Enzyme Cocktail Produced
Less Cohesive, More Easily Breakable Fecal Material

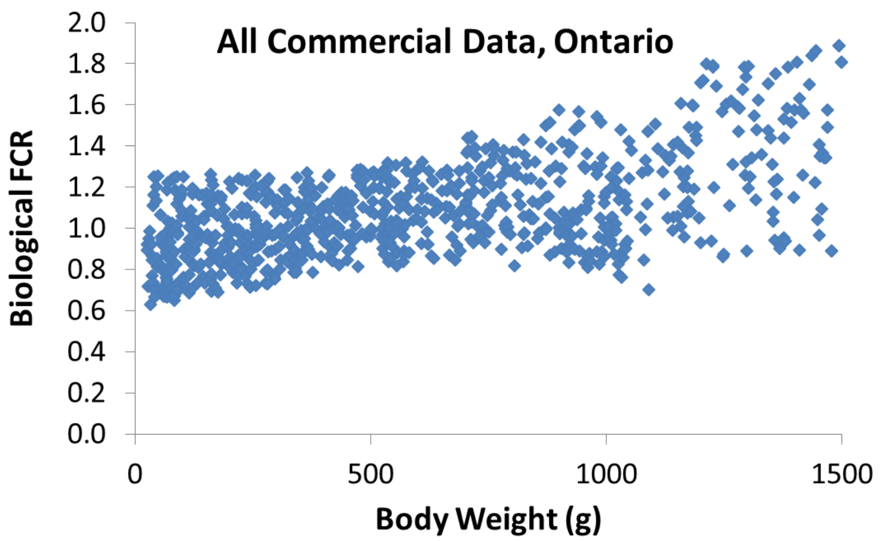
3. Improving production efficiency and minimizing or managing the release of wastes through improvement of feeding practices

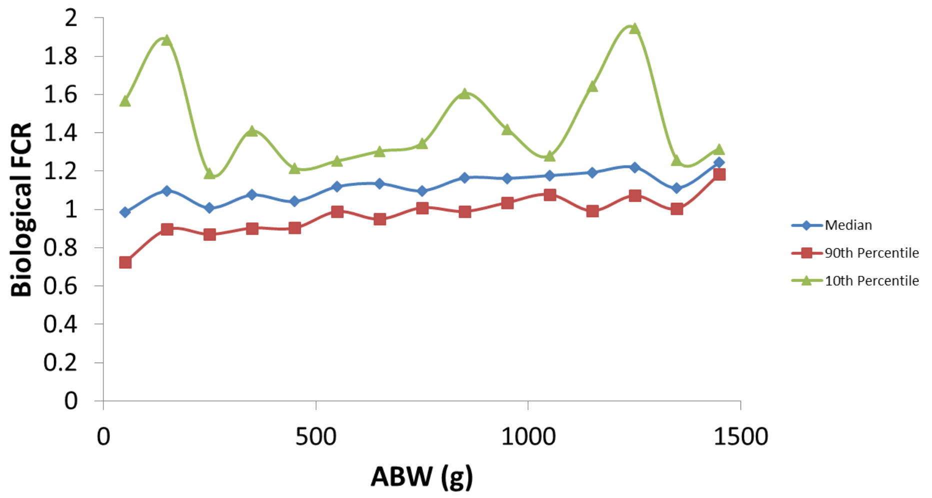
"Knowledge is of no value unless you put it into practice"

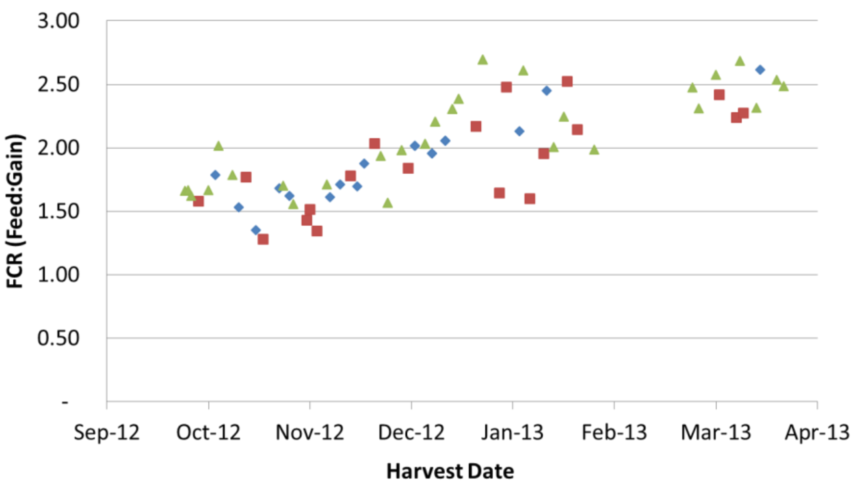
Anton Chekhov

Farm to Farm, Lot to Lot, Within Production Cycle Variability









Main Question

How Does “Feeding “ and “Environment” Affect Efficiency of Feed and Nutrient Utilization and thus Waste Outputs of Aquaculture Species?

The question often explained using an “energy” angle

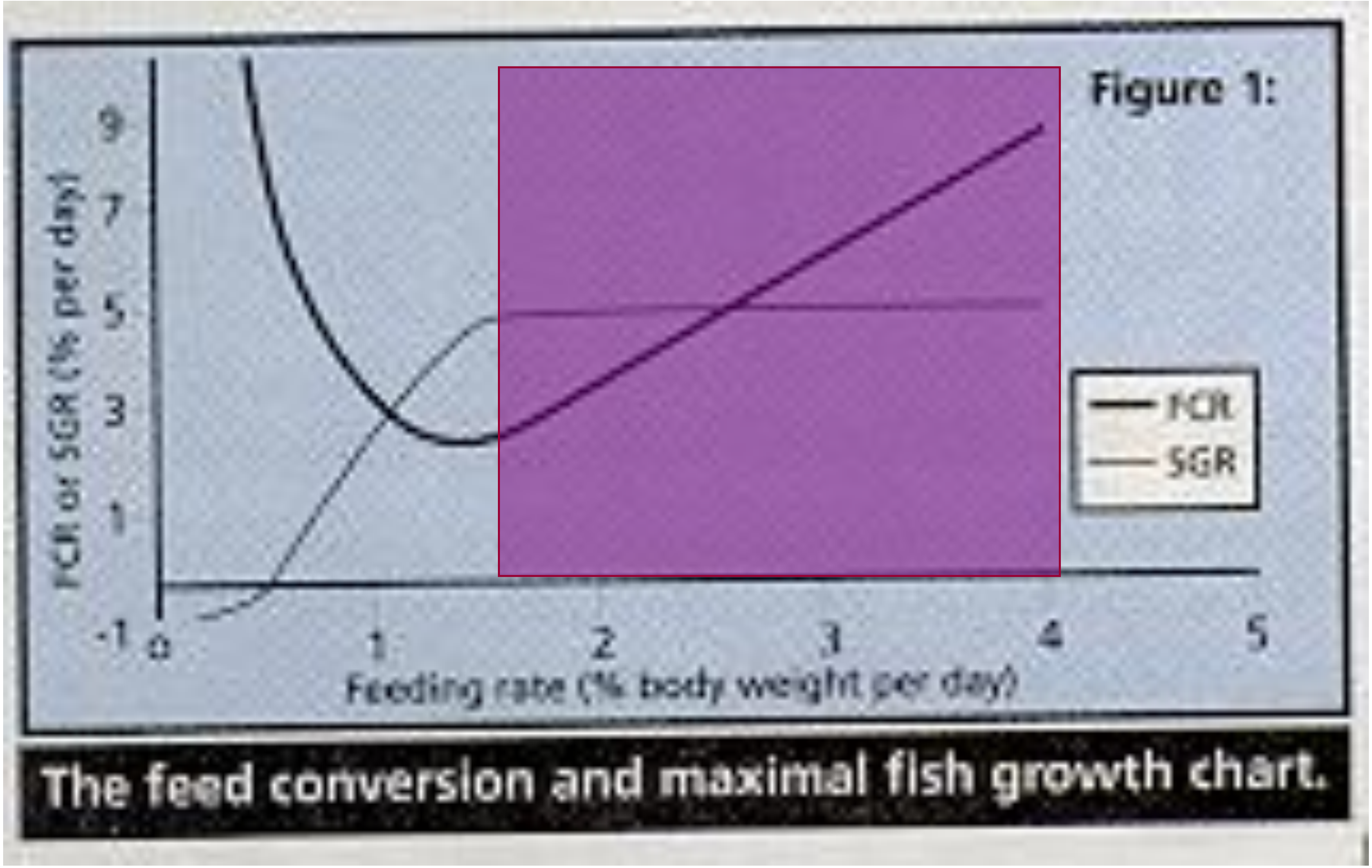
Bioenergetics is based on hierarchy of energy allocation

“Growth is the surplus of energy after all other components of the energy budget have been covered or satisfied”

Elliott (1999)

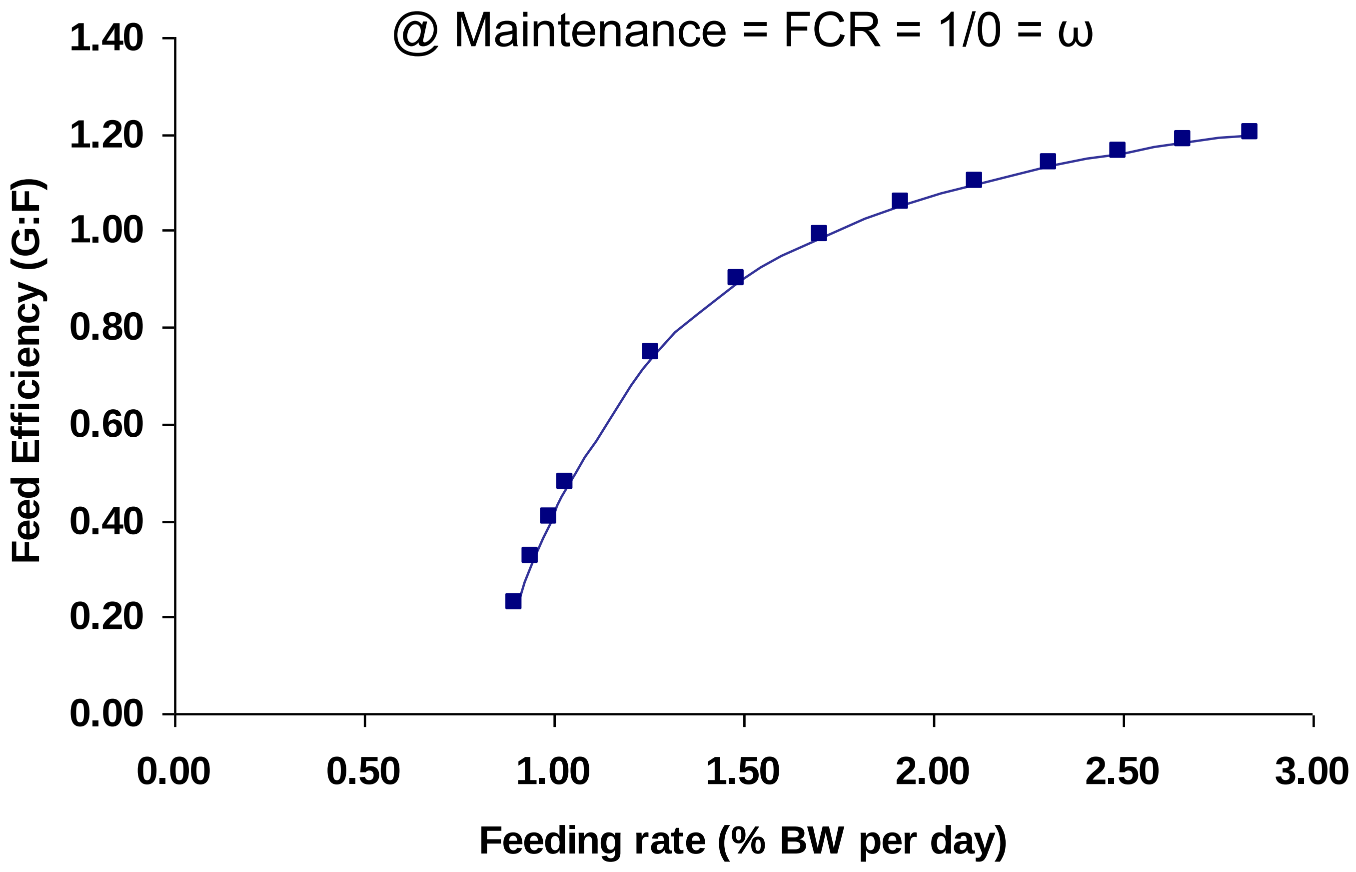
Fish fed **decreasing rations** should have increasingly **less good** feed efficiency.

Feeding, Growth and Feed Efficiency / FCR?



Talbot (1993), Einen (1995)

Theoretical Effect of Feeding Level on Feed Efficiency
Fish-PrFEQ Model Simulation



Are these predictions realistic?

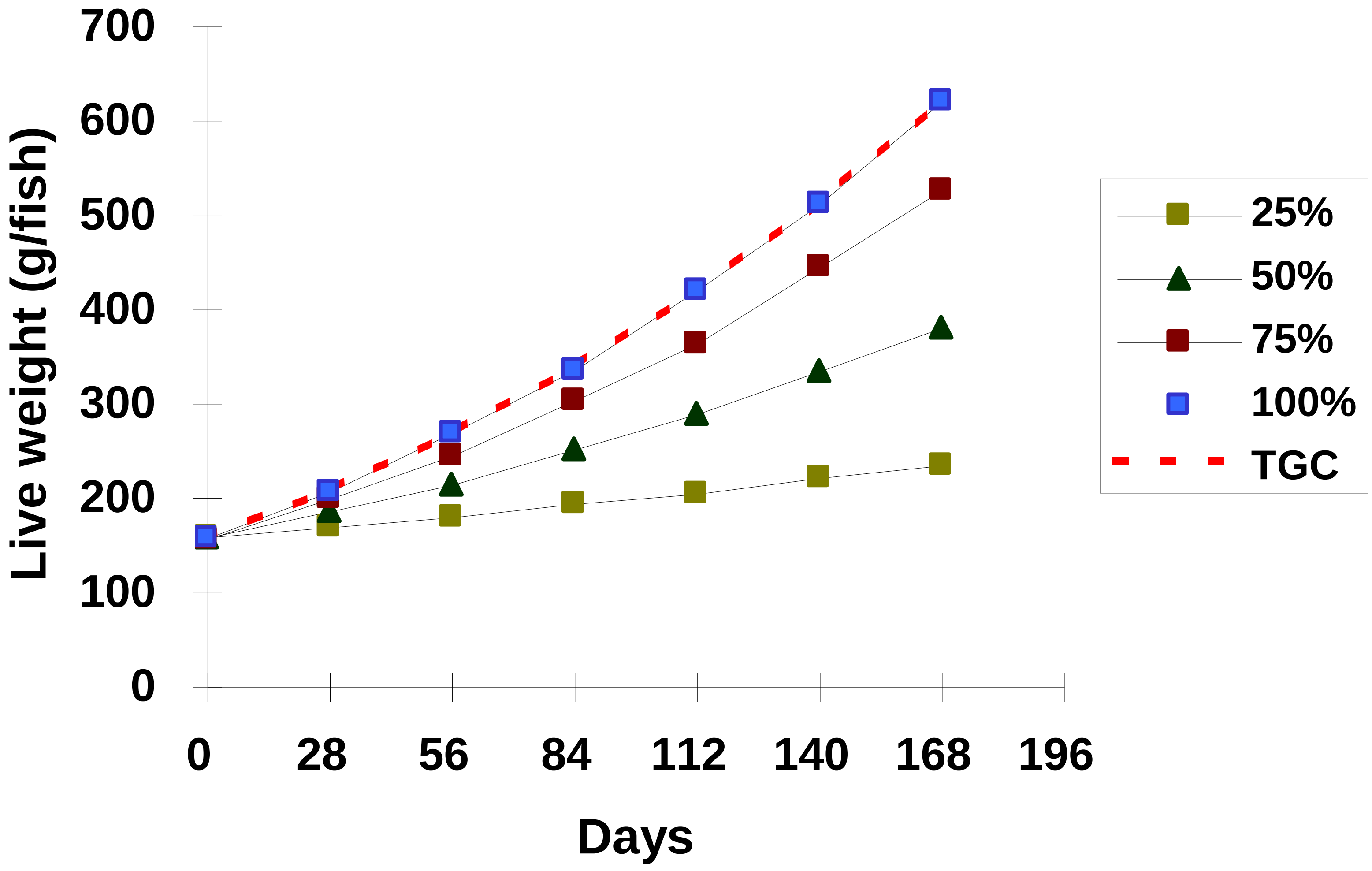
Effect of Feeding Level on Performance of Rainbow Trout

	Feeding level (%)				Contrast	
Parameters	25	50	75	100	Lin	Quad
FBW, g/fish	235	381	526	621	0.001	0.05
Feed, g/fish	78	201	364	554	-	-
FE, gain:feed	0.98	1.08	1.02	0.83	0.001	0.001
TGC	0.054	0.130	0.188	0.220	0.001	0.001

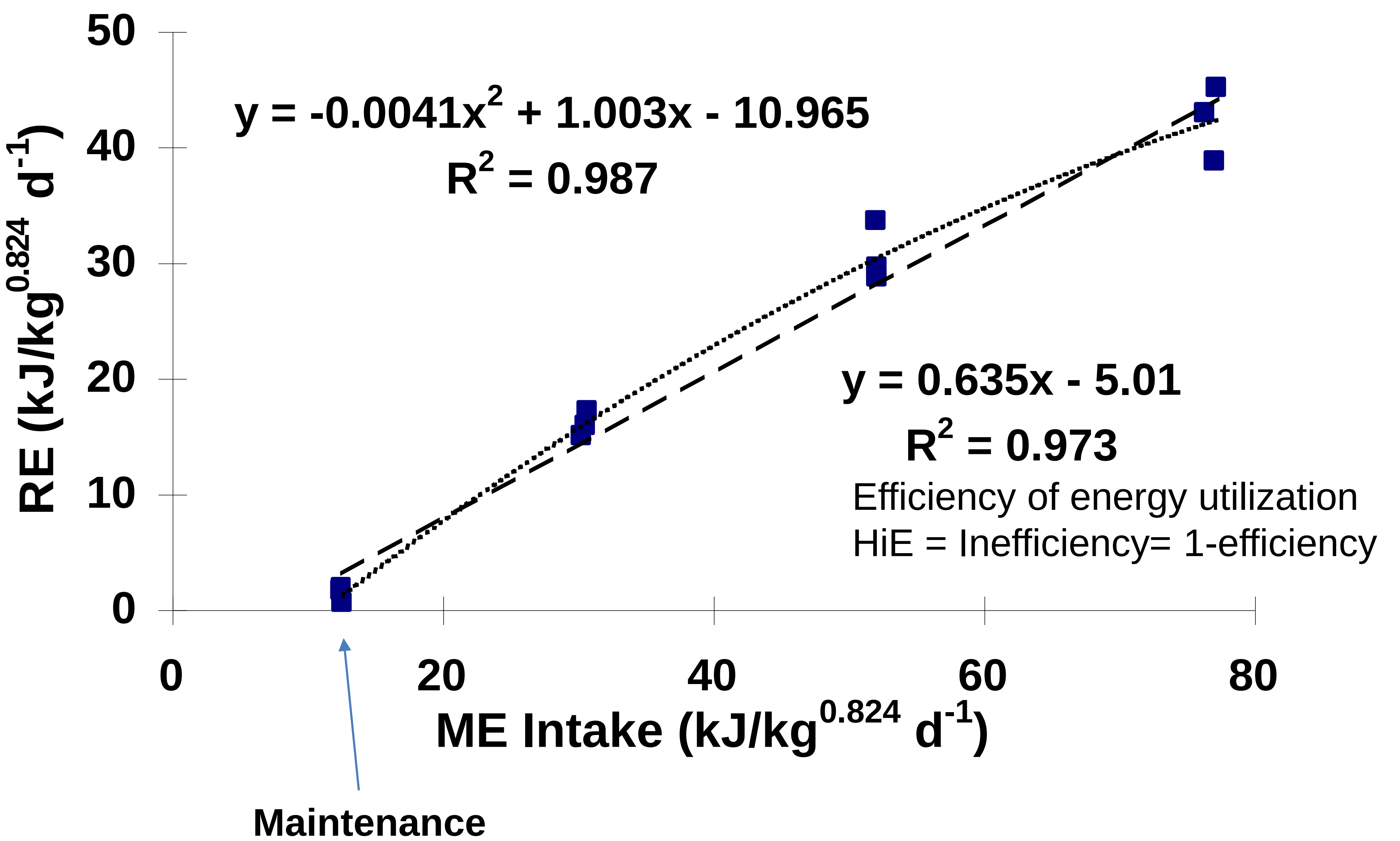
Initial body weight = 157 g/fish, duration = 24 week, water temp. = 8.5^{o}C

Bureau, Hua and Cho (2006)

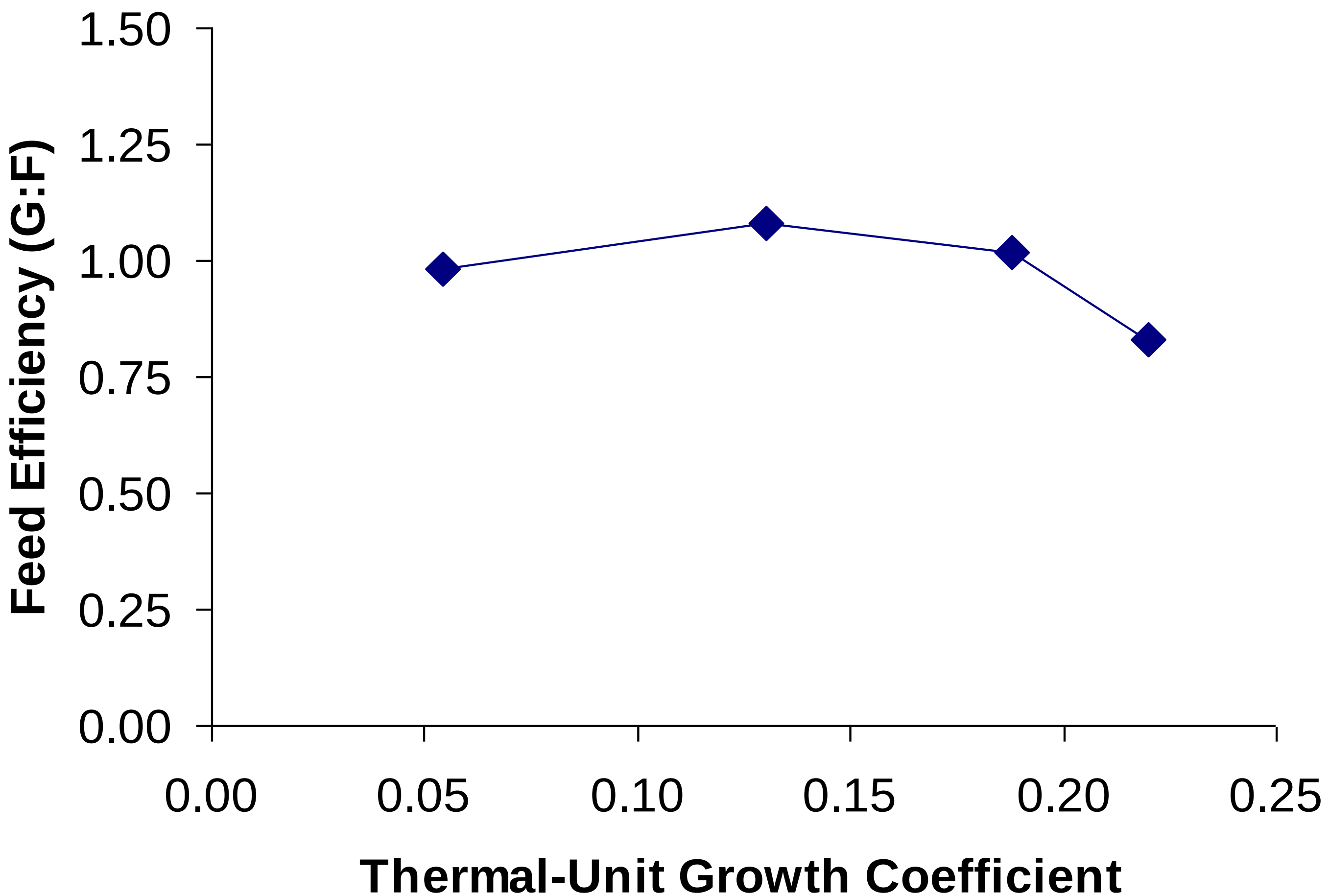
Growth of Rainbow Trout as a Function of Feed Ration Level



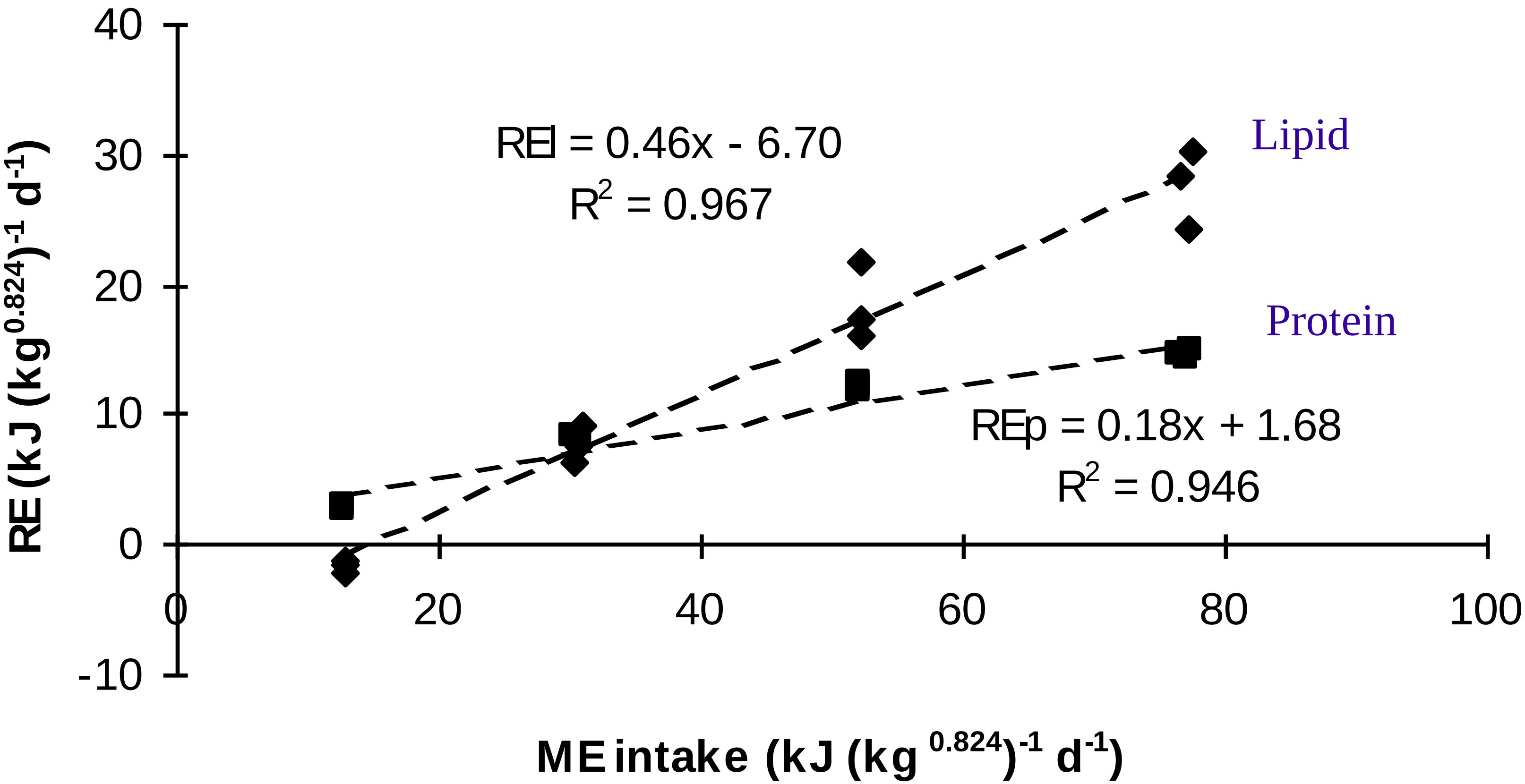
Comparative Carcass Analysis Approach (12 tanks, 4 feed



Effect of Feeding Level on Feed Efficiency

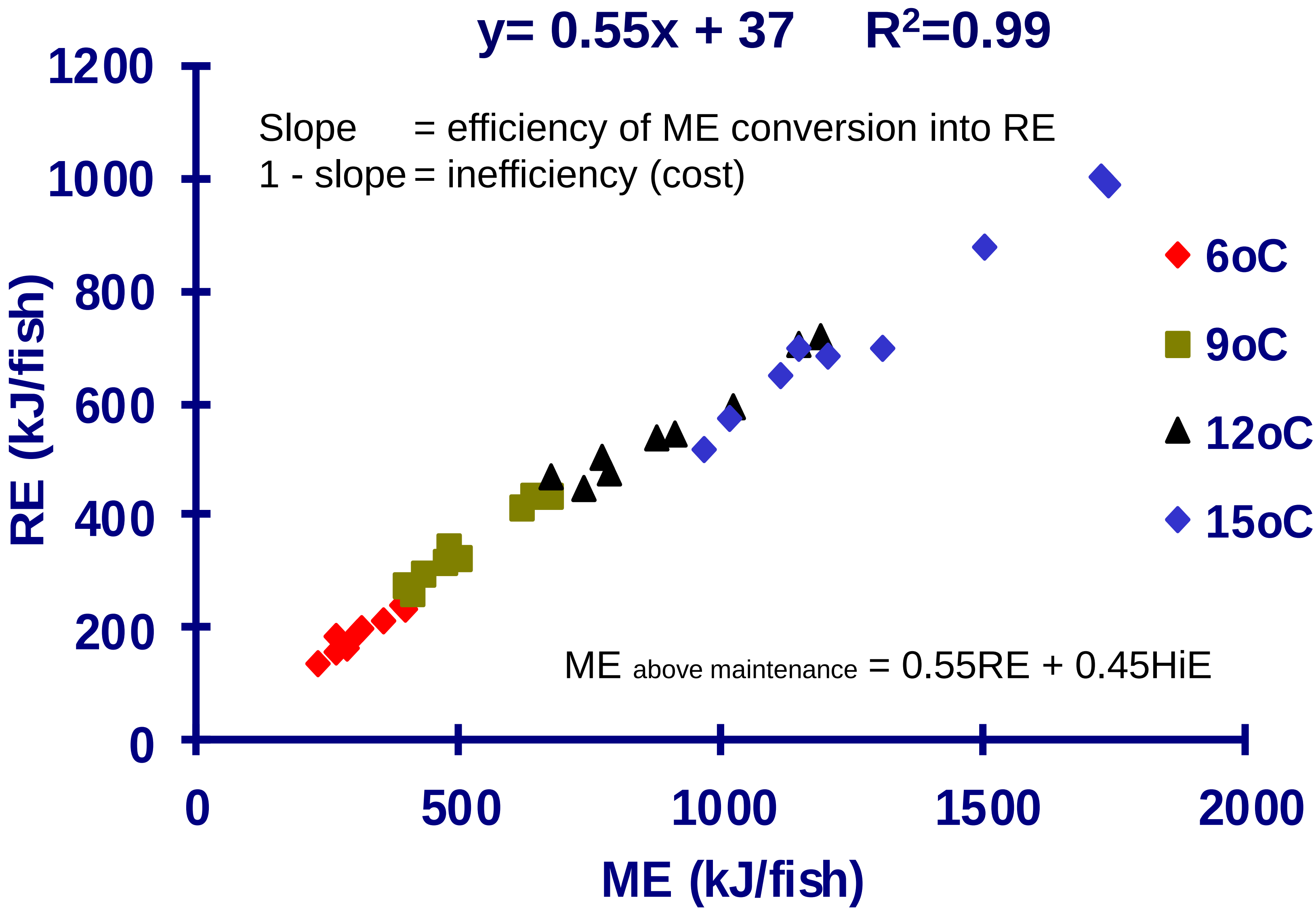


Decreasing feeding level did not have a major effect on feed efficiency! FCR remained around 1!!!



"Energy Gain" Lumps Two Separate Processes: Protein and Lipid Depositions!
Positive protein gain = positive weight gain

Bureau et al. (2006)



Feeding level and water temperature had no effect on efficiency of metabolizable energy (ME) utilization

Feeding Management

Key Issues :

Feeding management = Often more about people management than animal management!

Significant farm to farm, lot to lot variability

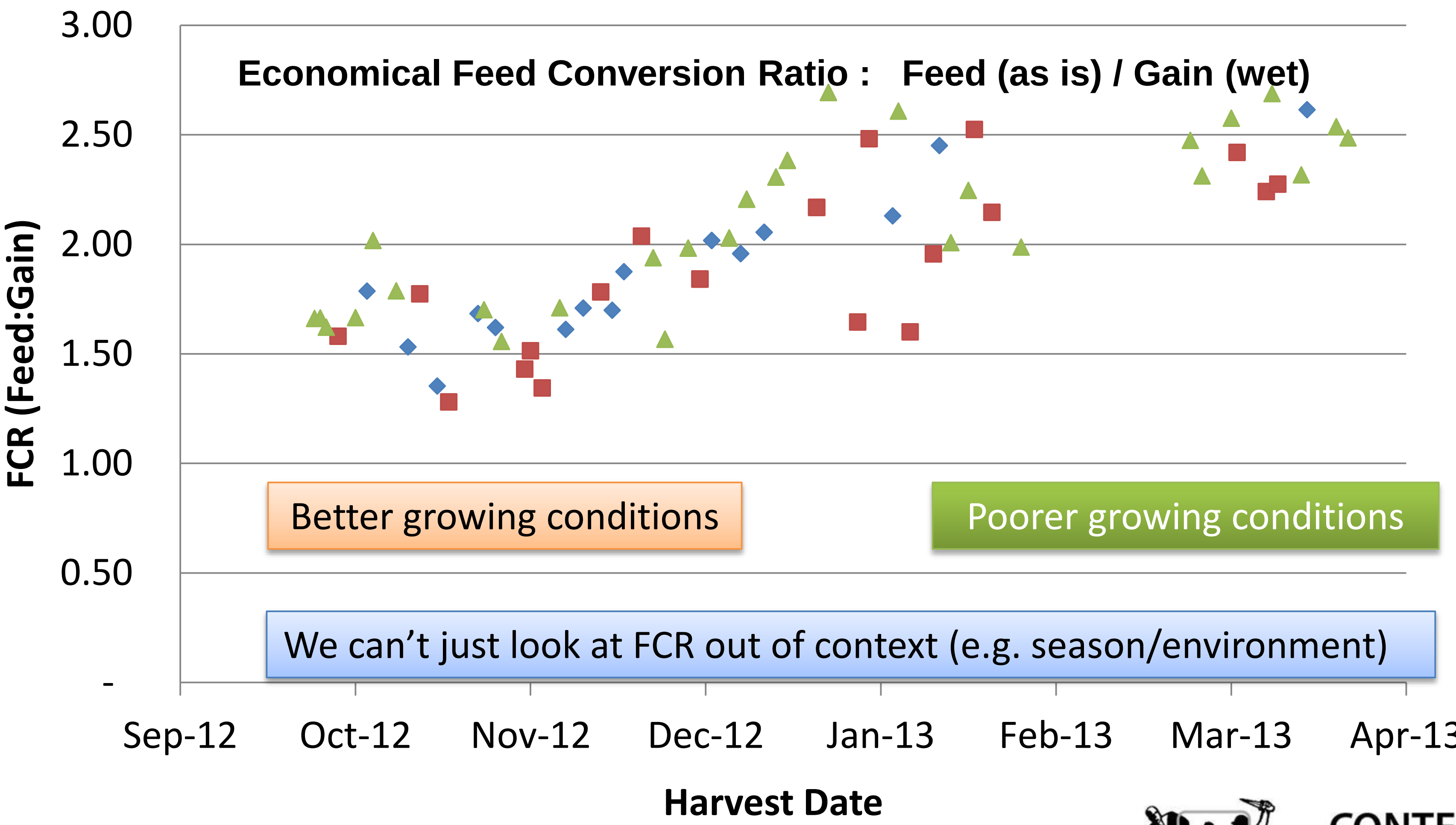
- Differences in production management and feeding practices?
- Different environmental factors limiting efficiency?

Strategies:

Examine management and environment factors influencing efficiency of feed utilization

Improve effectiveness of production and feeding management on farms (supervision, practices, training, tools, etc.)

FCR of Tilapia Produced on Different Aquaculture Operations

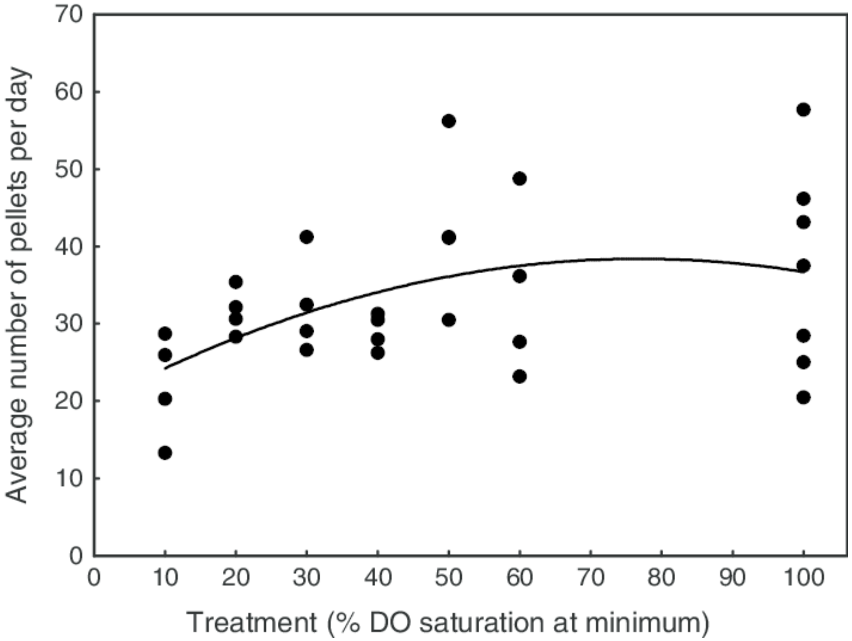


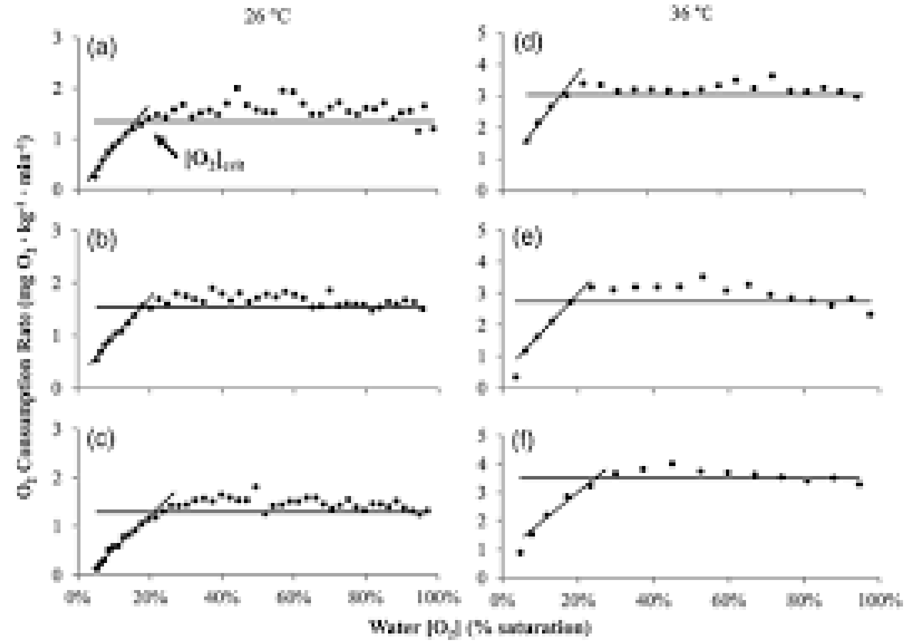
More information can be extracted with systematic organization and analysis of information

CONTEXT

Remember:
A single statistic doesn't tell the whole story.

Dissolved Oxygen





Take home message:

Dissolved oxygen level below a threshold results in significant decrease in performance. Oxygen is an essential “nutrient” to metabolism.

Too little DO, even occasionally, will hinder performance and may have dire consequence on efficiency

Mass fish death in China, cause unknown…

Flonergia

http://www.flonergia.com

1) Water Inlet
2) Radial Air Injection for Enhancing Oxygenation
3) Axial Air Injection for Enhancing Water Lifting
4) Air & Water Outlet

Models = Potential Management Tools

Models could be very valuable for improving productive efficiency of aquaculture operations

Information from the lab or the field can be used to construct models

Analysis of available information using models can :

1) Highlight limitations of models and contribute to improving them
2) Held identify areas of improvement for production management practices

Never blindly believe "model outputs" or "field data" !!!

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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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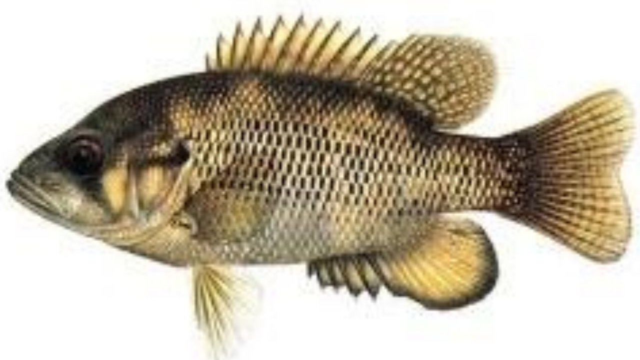
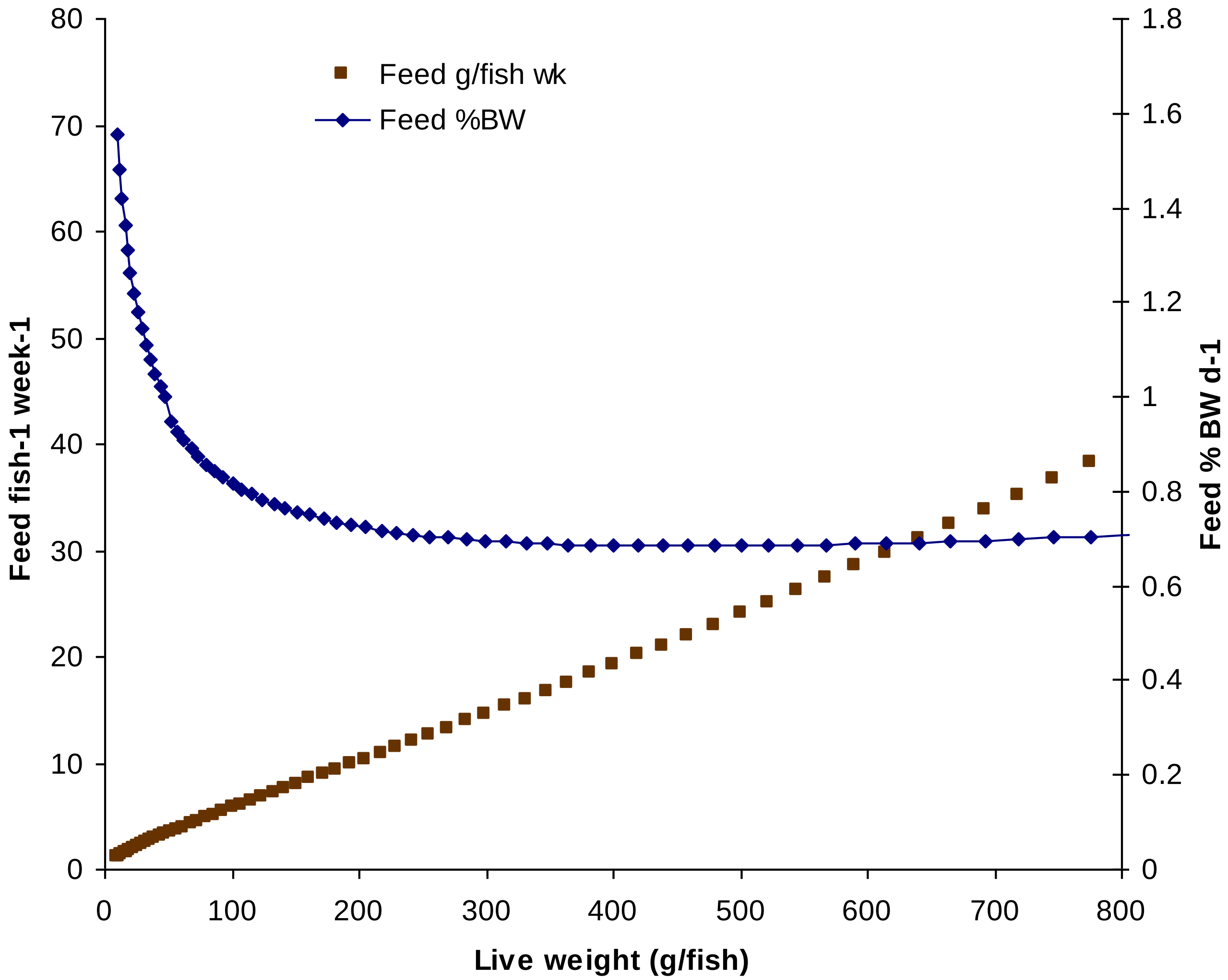


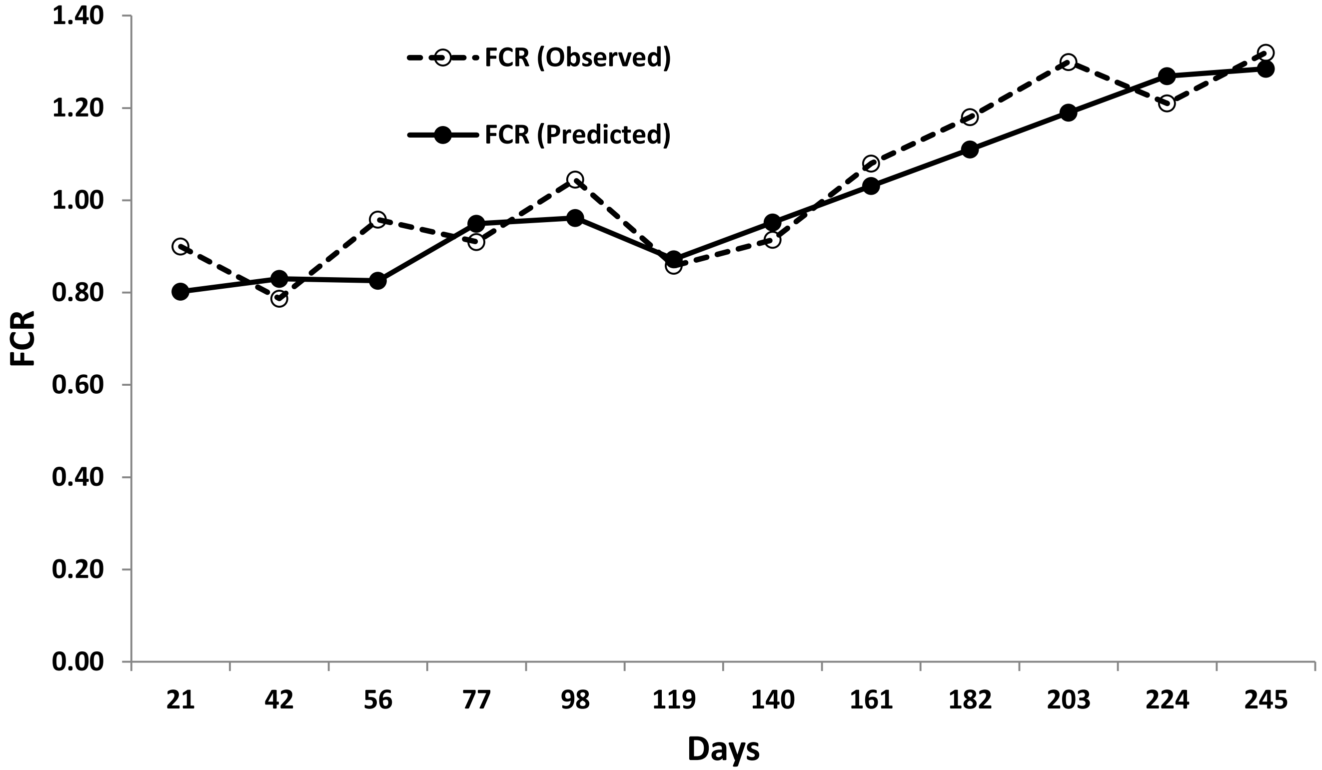
Dynamic Estimation of Feed Requirement of Rainbow Trout
(Flexible Feeding Chart)



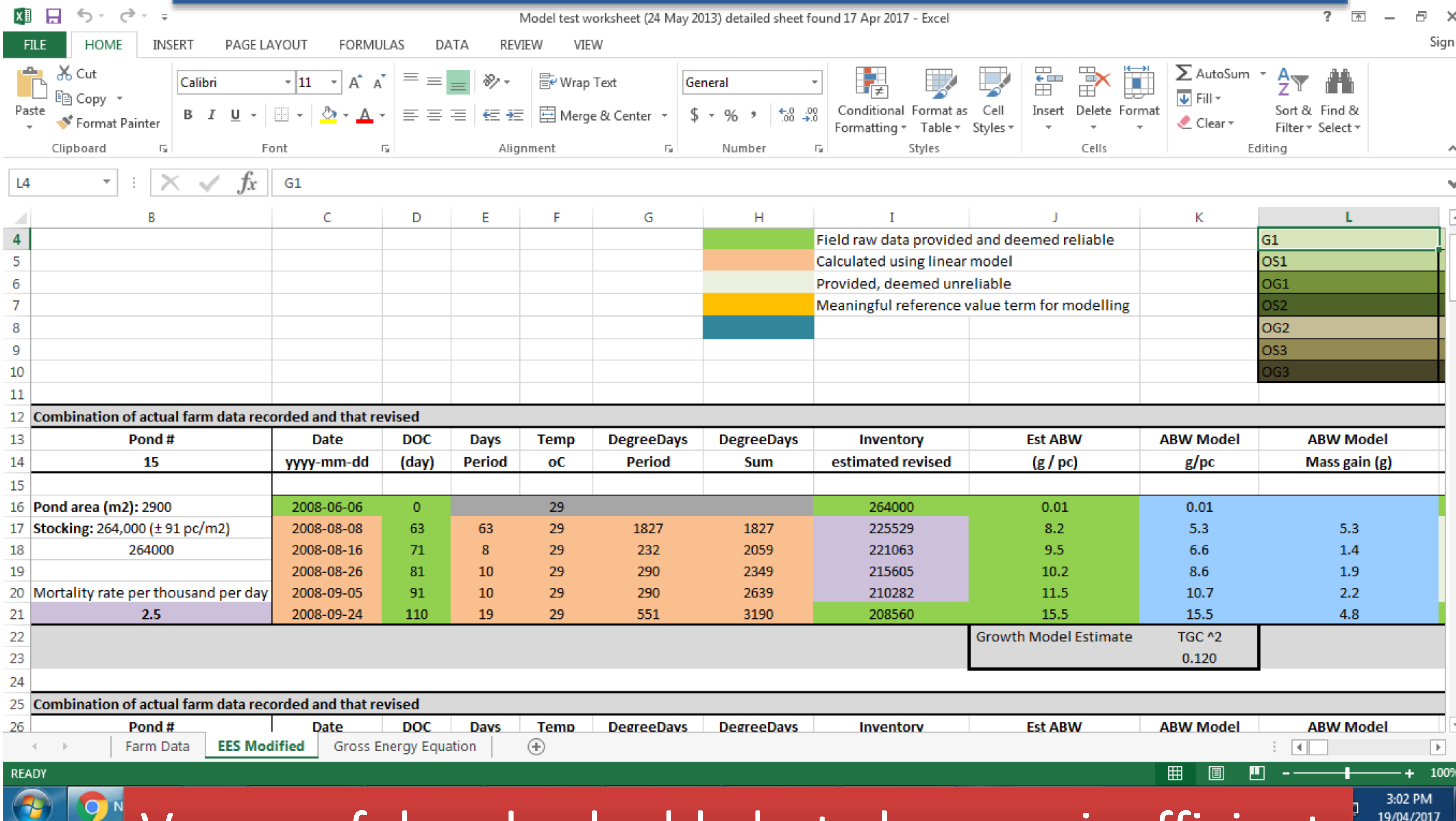
(TGC= 0.180, Temperature = 9ºC)

Bureau et al. (2002)

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



30 Years to Idiosyncratic Modeling and Analysis, Tool Development and Training at the University of Guelph



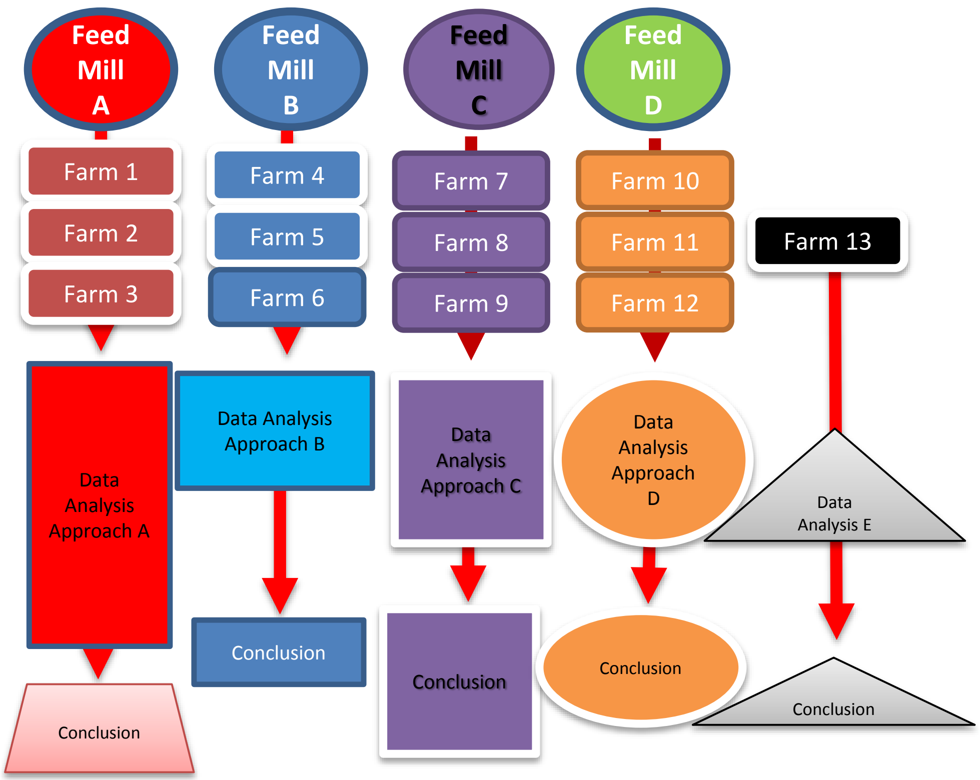
Pond #	Date	DOC	Days	Temp	DegreeDays	DegreeDays	Inventory	Est ABW	ABW Model	ABW Model
15	yyyy-mm-dd	(day)	Period	oC	Period	Sum	estimated revised	(g / pc)	g/pc	Mass gain (g)
Pond area (m2): 2900	2008-06-06	0		29			264000	0.01	0.01	
Stocking: 264,000 (± 91 pc/m2)	2008-08-08	63	63	29	1827	1827	225529	8.2	5.3	5.3
264000	2008-08-16	71	8	29	232	2059	221063	9.5	6.6	1.4
	2008-08-26	81	10	29	290	2349	215605	10.2	8.6	1.9
Mortality rate per thousand per day	2008-09-05	91	10	29	290	2639	210282	11.5	10.7	2.2
2.5	2008-09-24	110	19	29	551	3190	208560	15.5	15.5	4.8

Very useful and valuable but also very inefficient

Aquaculture Data Compilation and Analysis Systems

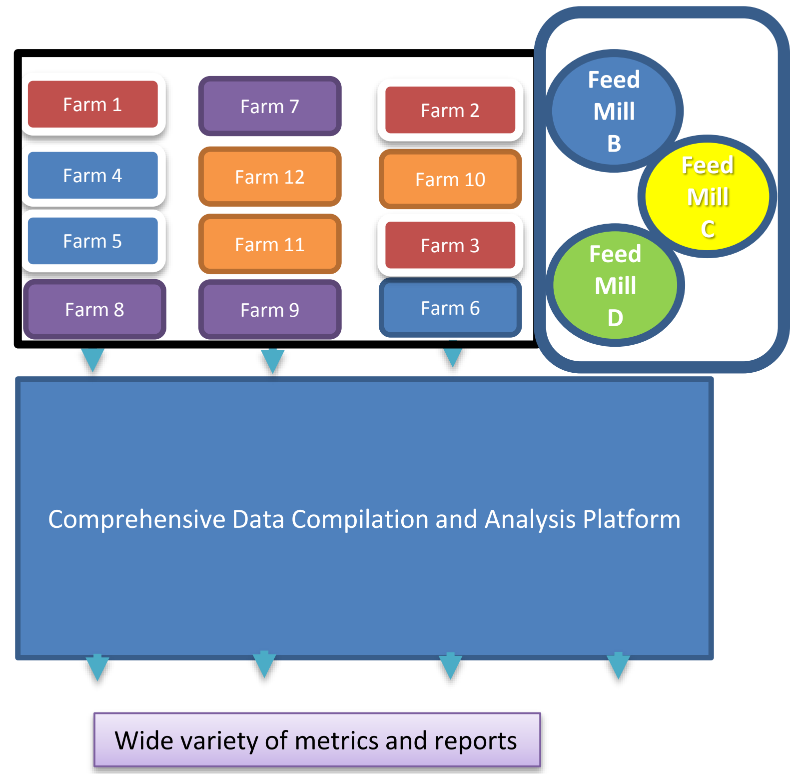
Current state-of-the-art in aquaculture

Idiosyncratic & Segmented Systems



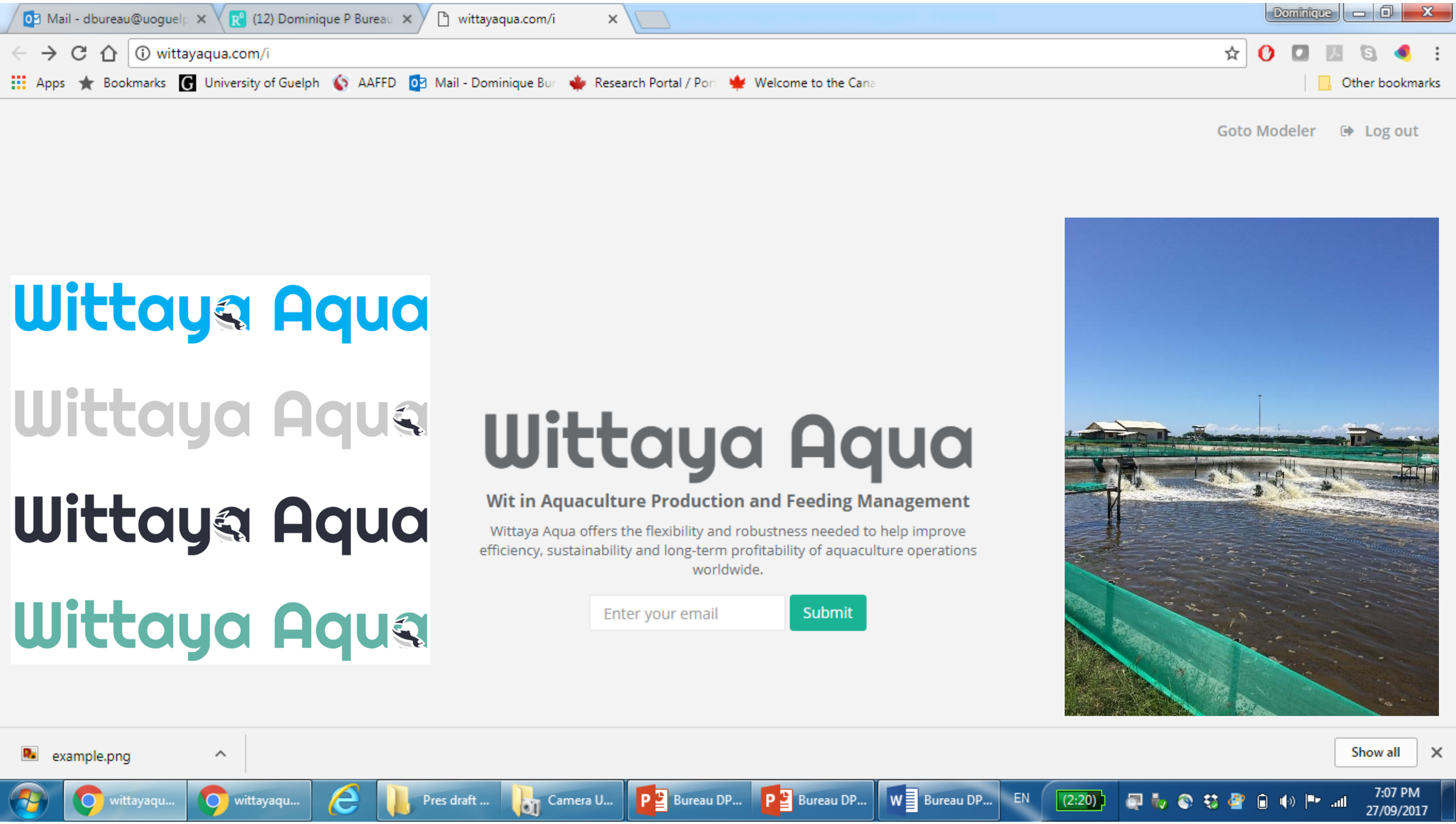
Idiosyncratic and hodgepodge conclusions

Alternative?
A Common, Standardized & Comprehensive Syst



Robust analysis and comparisons

My own effort to do something about the situation and opportunity



I failed twice already so this third time is a charm!

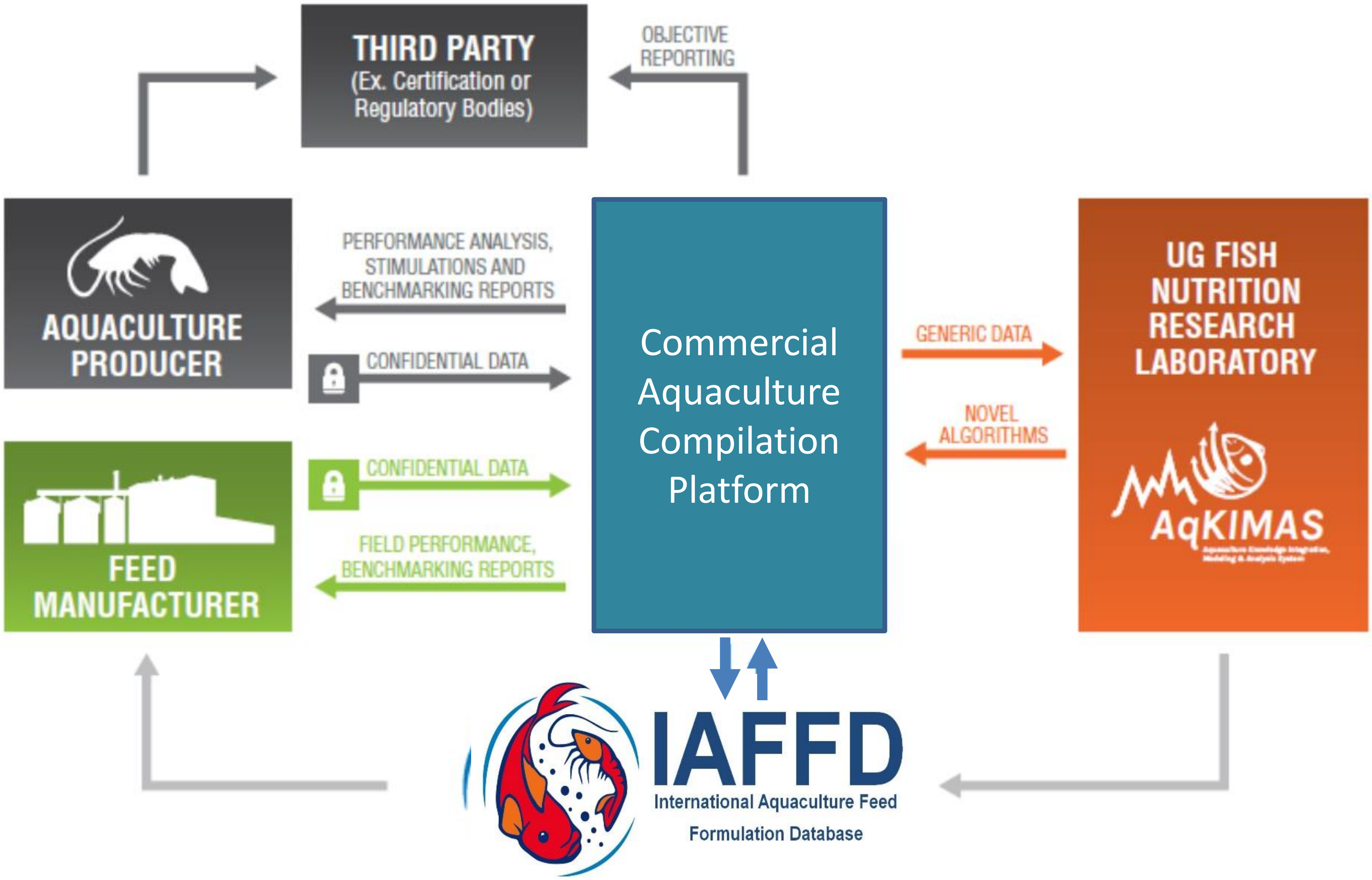
Wittaya Aqua Simply Uses "Typical" Farm Growth + Feed Records Already Collected by Technical Field Staff

Growth performance and feed conversion of white pacific shrimp in East Java & Lampung

No	Pond Area (M2)	Stocking date	DOC (day)	Est ABW (g / pc)	Est SR (%)	Biomass (kg)	Feed consumed	Est FCR	Feed Type
1	Pond No:15	6/6/2008	63	8.2	76.0	1645.2	1423.0	0.86	S1
	2900 m2		71	9.5	91.0	2282.3	2134.0	0.94	G1
	Stock : 264,000 (± 91 pc/m2)		81	10.2	97.0	2612.0	2839.0	1.09	G1
	Hatchery : PPM		91	11.5	95.7	2905.5	3628.0	1.25	G1
			110	15.5	79.0	3232.7	4210.0	1.30	G1
2	Pond No:16	6/6/2008	63	7.5	82.0	1494.5	1262.0	0.84	S1
	2500 m2		71	8.6	97.0	2027.1	1913.0	0.94	G1
	Stock : 243,000 (± 97 pc/m2)		81	9.5	100.0	2308.5	2572.0	1.11	G1
			91	10.2	98.5	2441.4	3243.0	1.33	G1
			109	13.5	75.0	2460.4	4140.0	1.68	G1

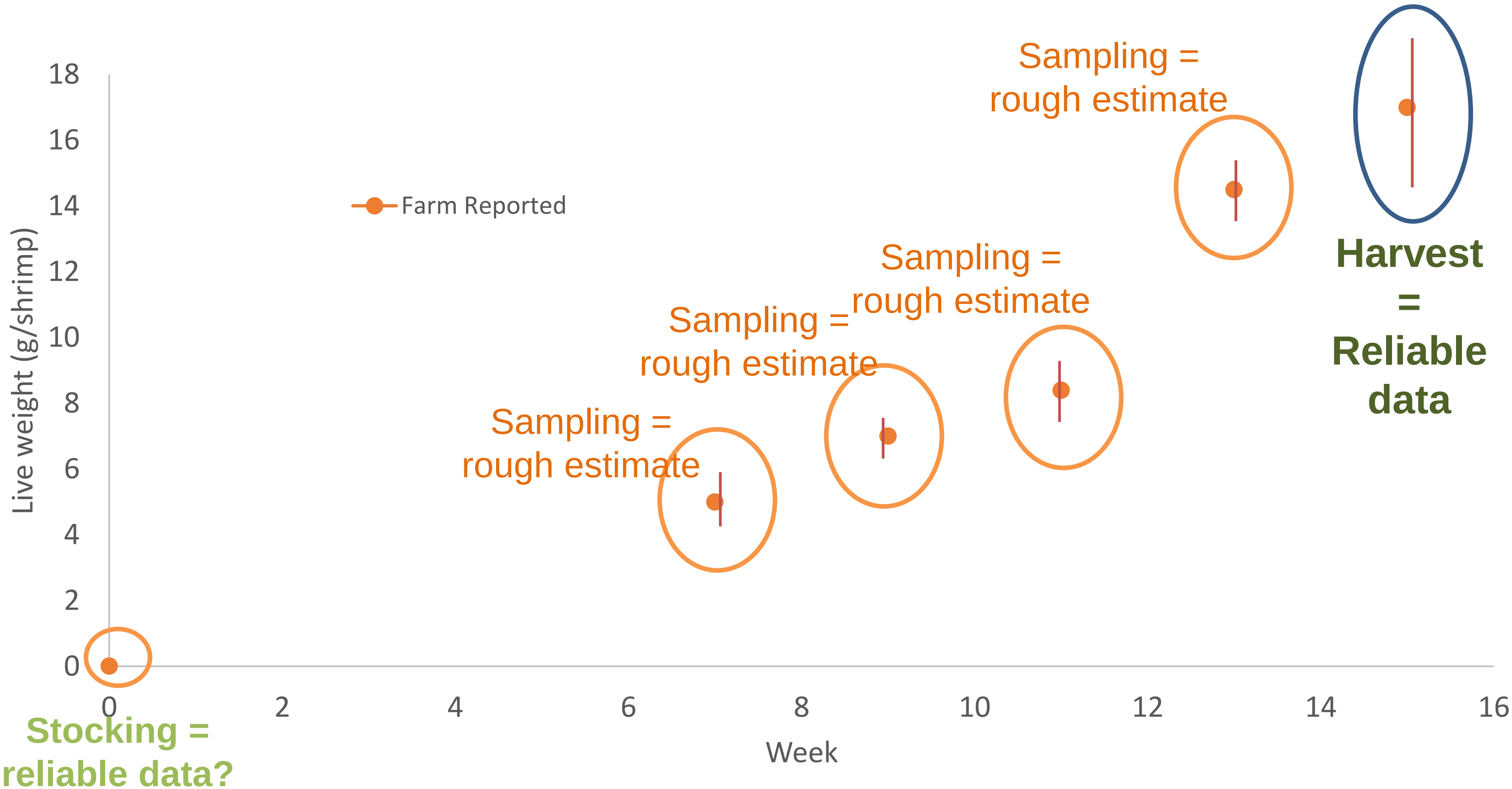
Conceptual Architecture of Wittaya Aqua

Wit in Aquaculture production and Feeding Management

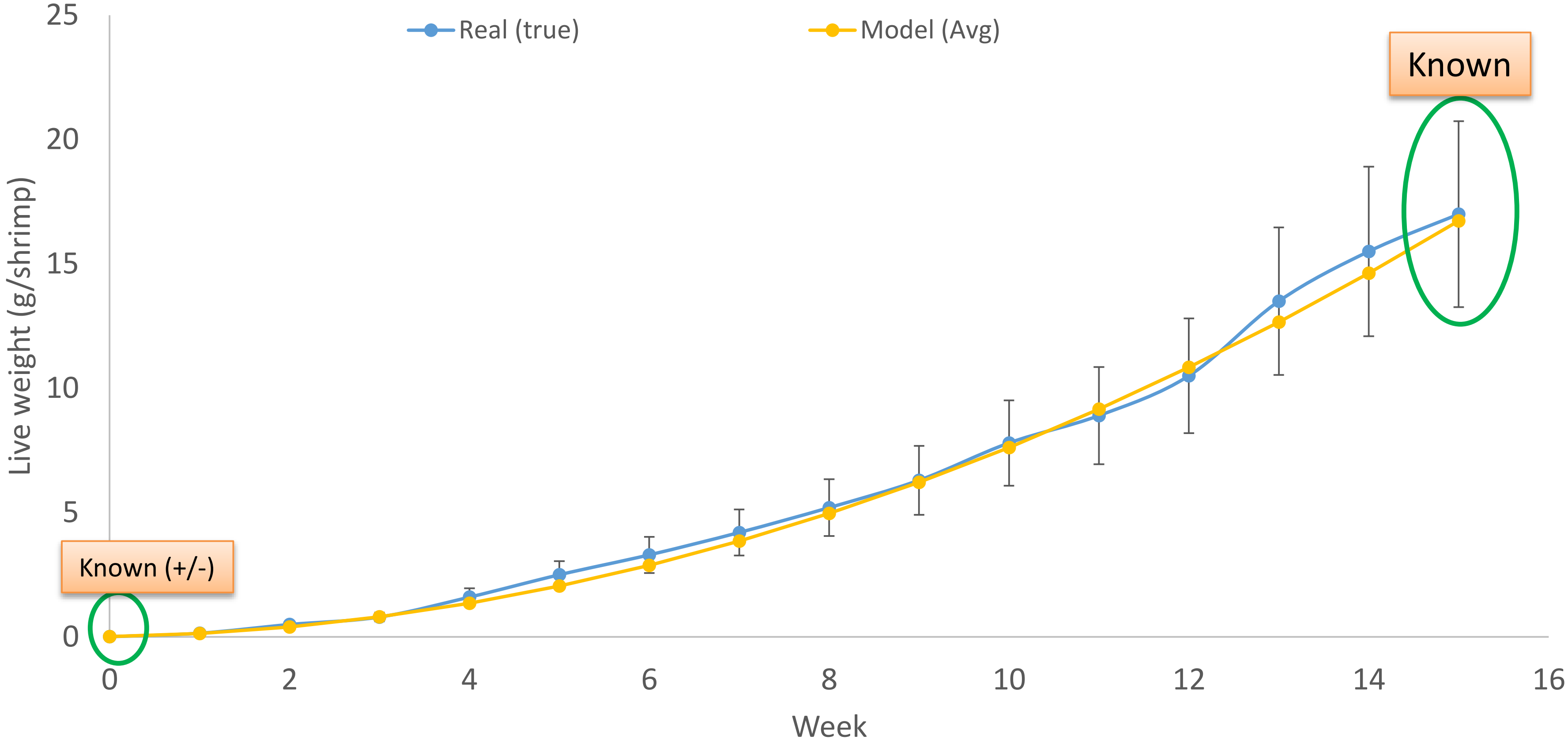


Typical Shrimp Farm Data

Estimates of live weight



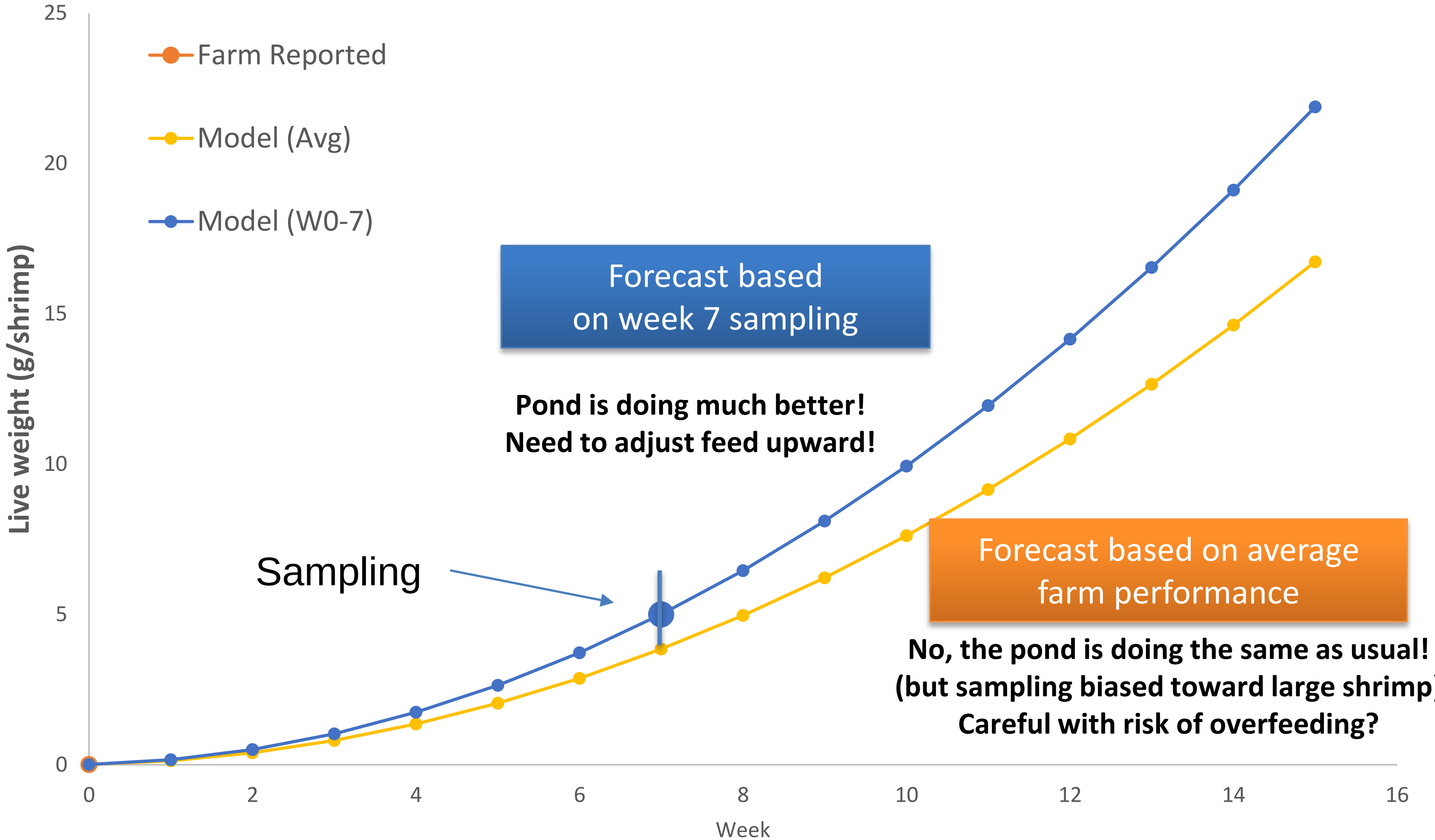
The expected growth trajectory of L. vannamei based on farm average and estimated growth trajectory of one production lot



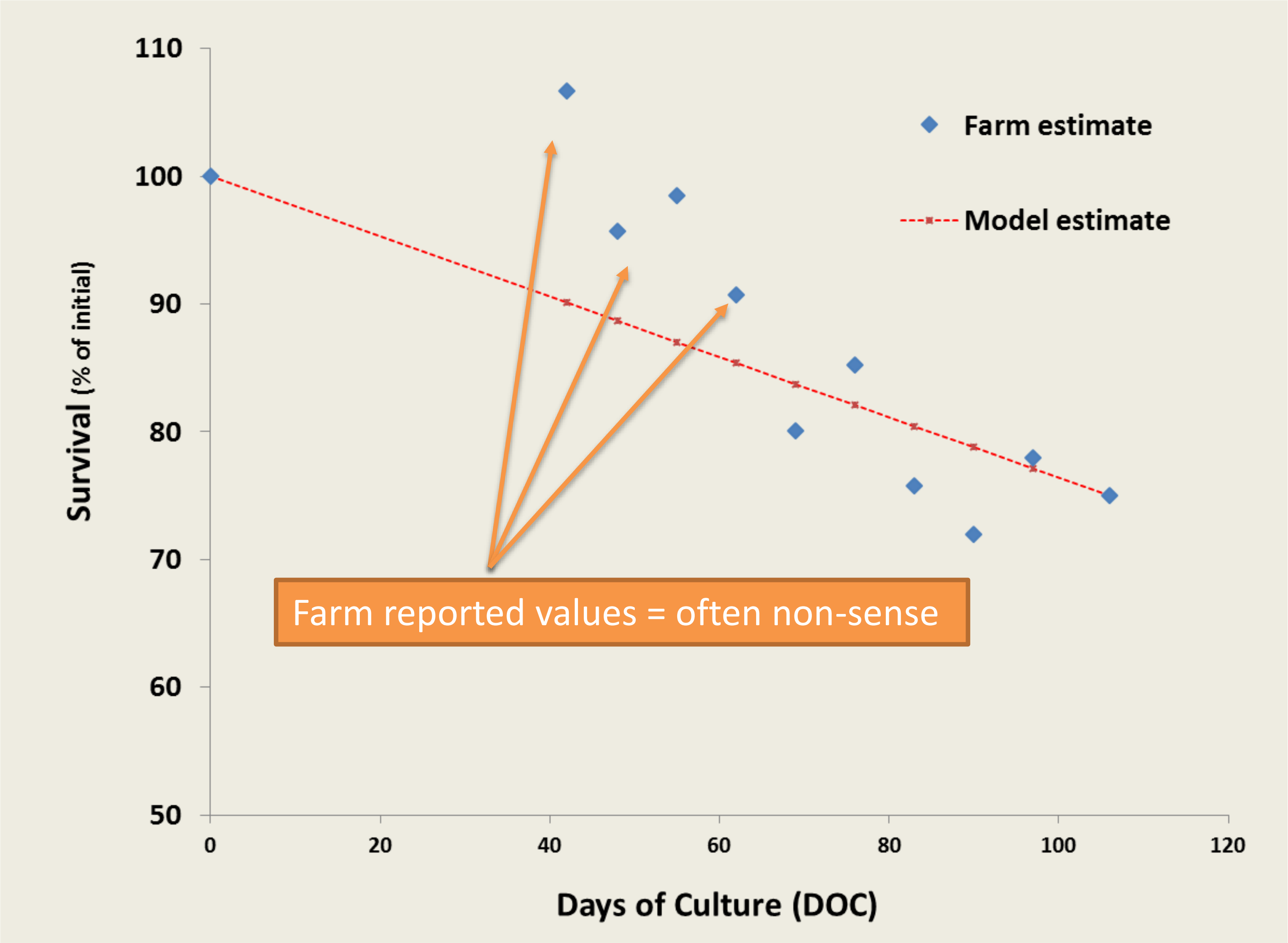
Most these points in between are just rough estimates. Should we care?
Any value in having reasonable estimates?

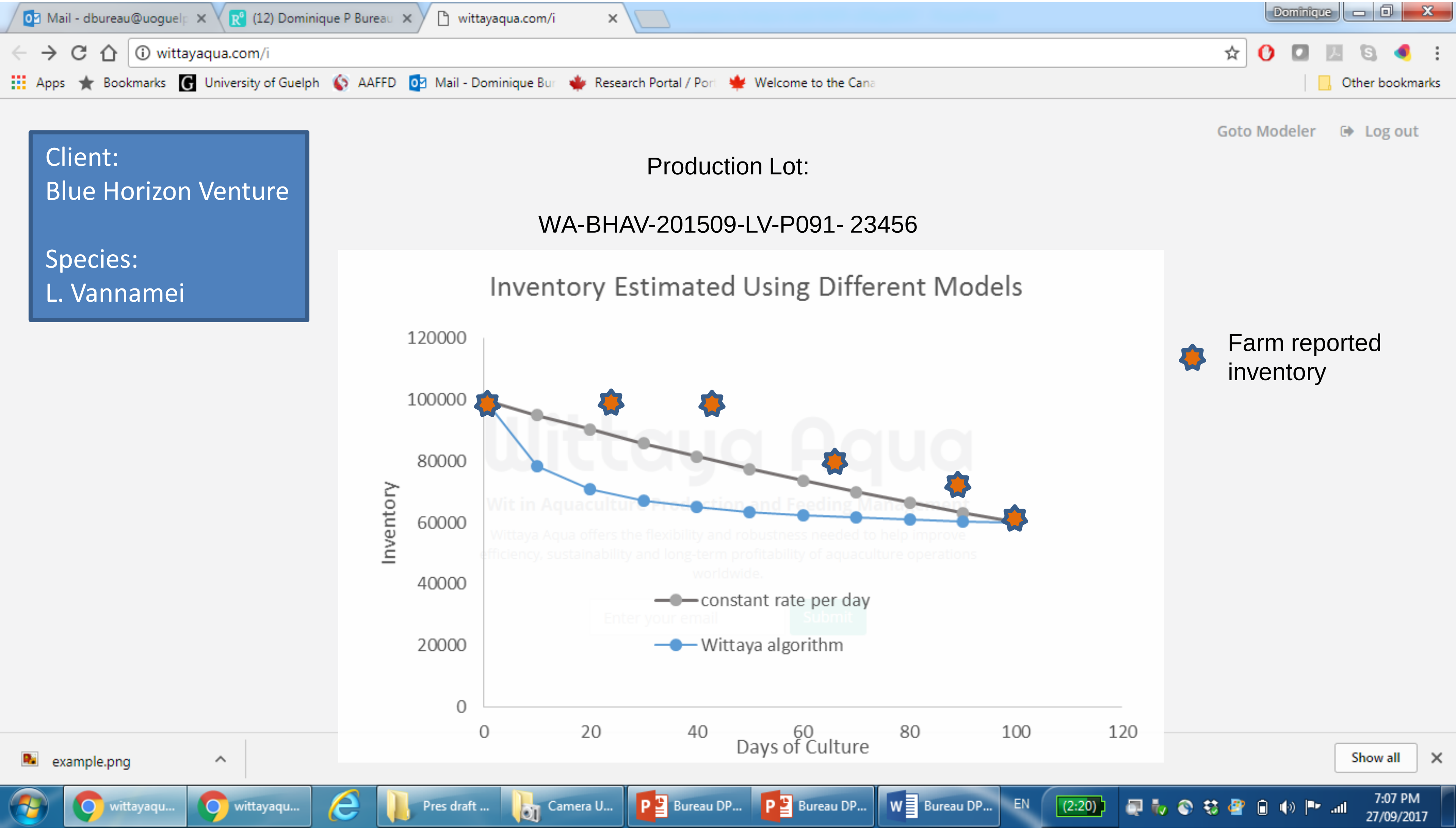
Scenario: Testing a new PL source, a new feed or different production protocol

Forecasting Growth of Shrimp Based on first Sampling Weight vs. Farm Average Performance



The Challenge of Inventory Management





wittayaqua.com/i
Goto Modeler
Log out
Client:
Blue Horizon Venture
Species:
L. Vannamei
Production Lot:
WA-BHAV-201509-LV-P091- 23456
Inventory Estimated Using Different Models
Inventory
Days of Culture
constant rate per day
Wittaya algorithm
Farm reported inventory
example.png
Show all

Wittaya Aqua
Wittaya Aqua
Wittaya Aqua
Wittaya Aqua

The Economic Angle

What if…

Parameters		Scenario 1 Industry Average	2 Poorer TGC	3 Better TGC	4 Poorer FCR	5 Best FCR	6 Higher Mortality	7 Lower Mortality
Thermal-Unit Growth Coefficient	TGC	0.185	0.165	0.195	0.185	0.185	0.185	0.185
FCR, feed:gain	F:G	1.29	1.29	1.29	1.35	1.22	1.29	1.29
Mortality	%	15	15	15	15	15	20	10
Days of culture	days	**366**	**410**	**347**	**366**	**366**	**366**	**366**
Profitability								
Profits	$/crop	**235,939**	**59,309**	**310,667**	**141,043**	**346,651**	**231,971**	**239,907**
Relative to Industry Average	%	**100**	**25**	**132**	**60**	**147**	**98**	**102**
Wastes								
Total Solid Wastes (TSW)	t/crop	303	303	303	317	286	303	303
Total Nitrogen Wastes (TNW)	t/crop	67	67	67	71	62	66	67
Total Phosphorus Waste (TPW)	t/crop	10.3	10.3	10.3	11.0	9.6	10.3	10.3

Assumptions : Water temperature = 11.5°C, feed cost = $1,600/tonne, market weight = 1000 g, Target production = 1,000 t/crop (± 1 year), Price of fish (round) = 3.85/kg, Fixed production costs of $1.33 million on annual (365 d) basis

Take Home Message

- Important to assess how well/poorly farming operations are truly doing. Significant farm to farm variability, most effective step is to determine the cause of this variability
- Waste outputs can be estimated using simple nutritional principles, environmental impacts = a lot more difficult
- Fine-tuning feed composition and judicious selection/use of ingredient and additives can results in significant reductions in FCR and/or waste outputs
- Efficiency of feed & nutrient utilization is generally very stable across feeding levels and environmental conditions
- Limiting environmental conditions (e.g. dissolved oxygen) and feeding practices are most important

Acknowledgments

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Fats and Proteins Research Foundation (FPRF)
MITACS
Martin Mills
Aqua-Cage Fisheries Ltd.