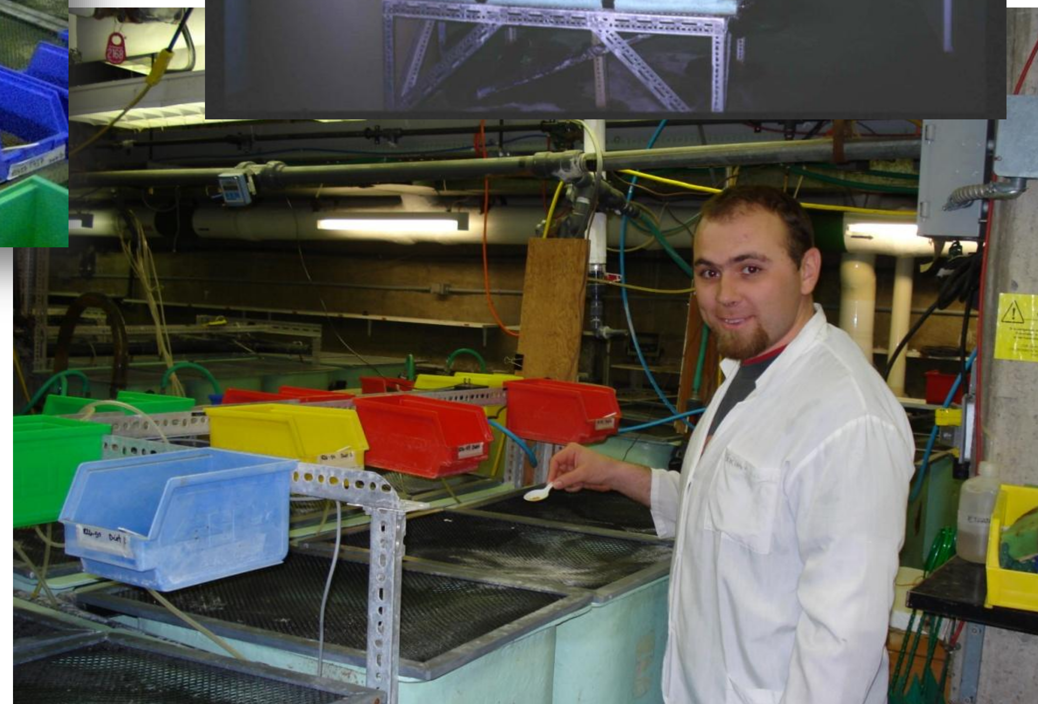


Fish Nutrition Research Lab

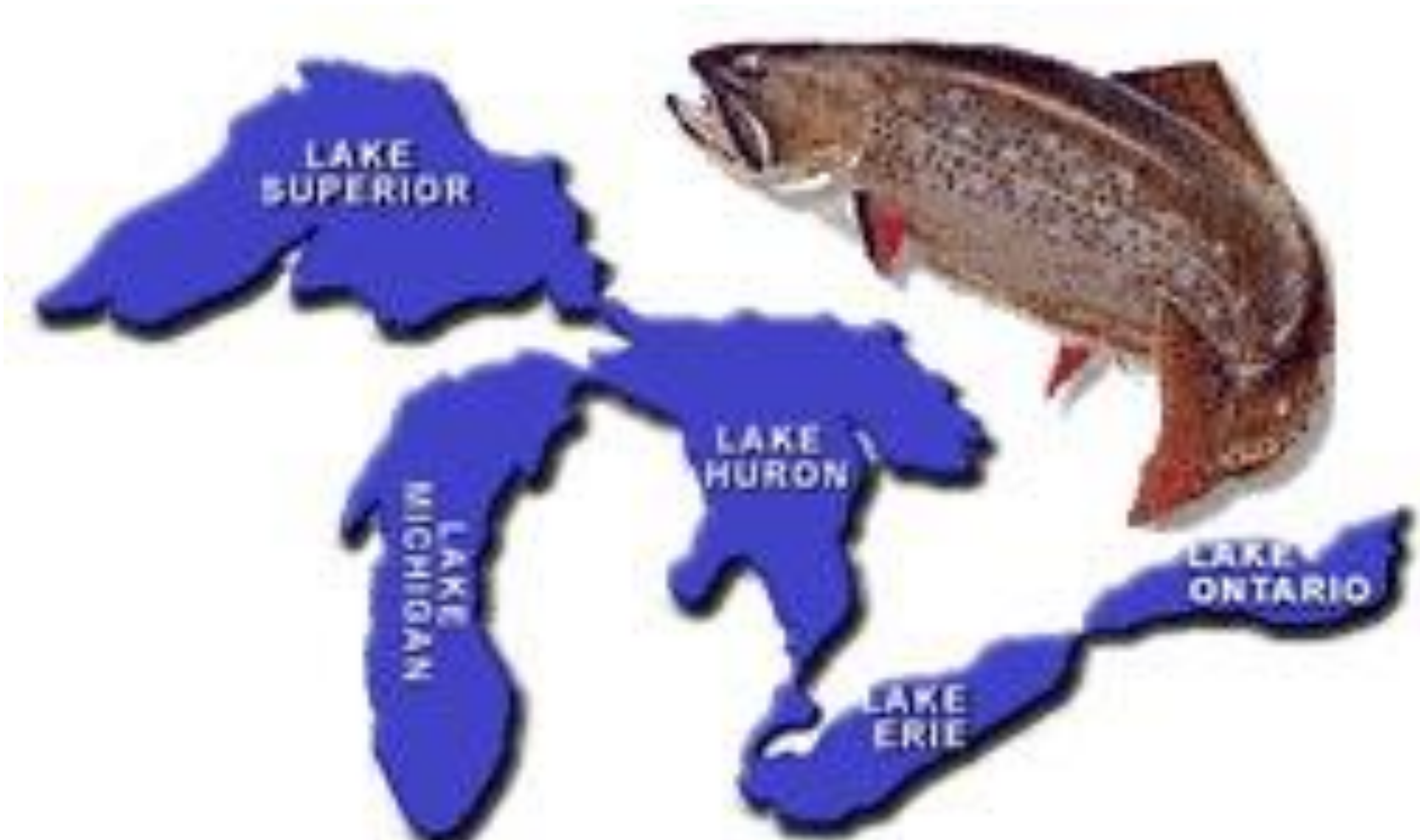
Dept. Animal and Poultry Science, University of Guelph | Ontario Ministry of Natural Resources

Fish Nutrition Research Lab

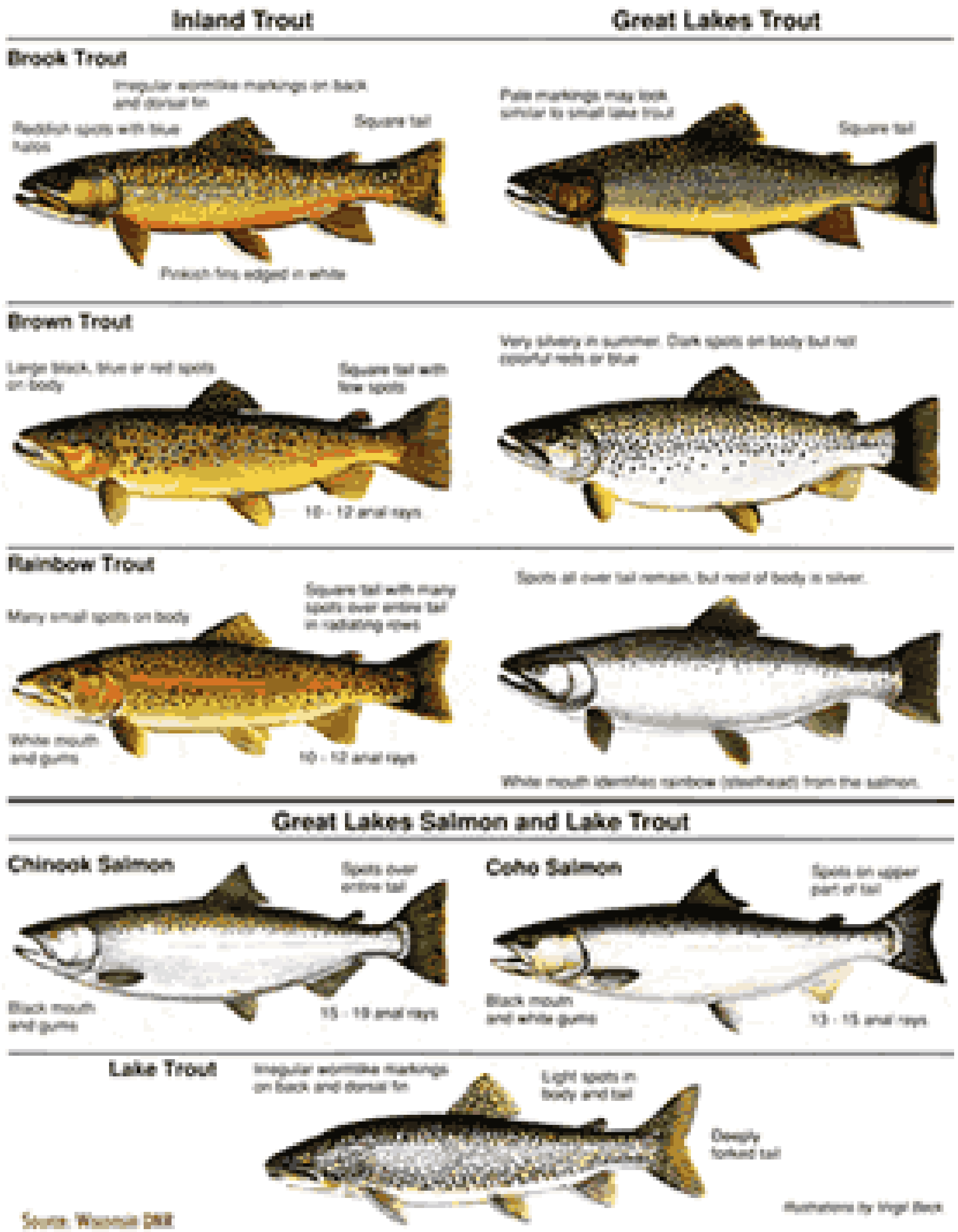
Dept. Animal and Poultry Science
University of Guelph | Ontario Ministry of Natural Resources

- In existence since 1969 (S.J. Slinger & C.Y. Cho)
- Historically regarded as a key fish nutrition lab.
  - Mind set, methodologies, equipment, feed formulae
- Sustained funding by government agencies and industry
  - Core funding from OMNR
  - OMAFRA, NSERC, Fisheries and Oceans, AquaNet
- Currently undergoing growth & youth movement
  - Hosted and trained100 graduate students, post-docs, & research assistants since 1992

Arctic Ocean
Ellesmere Island
Alert
North Magnetic Pole
Kalaallit Nunaat
(Grønland)
(Denmark)
Iceland
Bering Strait
Arctic Circle
Beaufort Sea
Banks I
Resolute
Baffin Bay
Arctic Circle
Alaska
(USA)
Inuvik
Victoria Island
Baffin Island
Davis Strait
Dawson
Great Bear Lake
Gjoa Haven
Yukon Territory
Whitehorse
Northwest Territories
Nunavut
Iqaluit
Labrador Sea
Mackenzie River
Yellowknife
Baker Lake
Ungava Bay
Atlantic Ocean
Fort Nelson
Great Slave Lake
CANADA
Nain
Newfoundland
British Columbia
Fort McMurray
Kuujjuaq
Prince George
Saskatchewan
Hudson Bay
Churchill Falls
Alberta
Churchill
St John's
Pacific Ocean
Edmonton
Manitoba
Sept-Îles
La Grande Rivière
Saint-Pierre et Miquelon (France)
Vancouver
Kamloops
Calgary
Sandy Lake
James Bay
Quebec
Victoria
Saskatoon
Prince Edward Island
Charlottetown
New Brunswick
Regina
Winnipeg
Thunder Bay
Ontario
Québec
Nova Scotia
Halifax
Fredericton
United States of America
Montréal
Ottawa
Lake Superior
Toronto
LEGEND
National capital
Provincial or Territorial capital
Other populated places
Lake Michigan
Lake Huron
Lake Ontario
Lake Erie
Scale
300 km 0 300 600 900 km



LAKE SUPERIOR
LAKE HURON
LAKE MICHIGAN
LAKE ONTARIO
LAKE ERIE


Inland Trout
Great Lakes Trout
Brook Trout
Irregular wormlike markings on back and dorsal fin
Reddish spots with blue halos
Square tail
Pinkish fins edged in white
Pale markings may look similar to small lake trout
Square tail
Brown Trout
Large black, blue or red spots on body
Square tail with few spots
10 - 12 anal rays
Very silvery in summer. Dark spots on body but not colorful reds or blue
Rainbow Trout
Many small spots on body
Square tail with many spots over entire tail in radiating rows
White mouth and gums
10 - 12 anal rays
Spots all over tail remain, but rest of body is silver.
White mouth identifies rainbow (steelhead) from the salmon.
Great Lakes Salmon and Lake Trout
Chinook Salmon
Spots over entire tail
Black mouth and gums
15 - 19 anal rays
Coho Salmon
Spots on upper part of tail
Black mouth and white gums
13 - 15 anal rays
Lake Trout
Irregular wormlike markings on back and dorsal fin
Light spots in body and tail
Deeply forked tail
Source: Wisconsin DNR
Illustrations by Virgil Beck

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

Talking about Nutrition

Dominique P Bureau

dbureau@uoguelph.ca

Fish Nutrition Research Lab

Dept. Animal and Poultry Science
University of Guelph

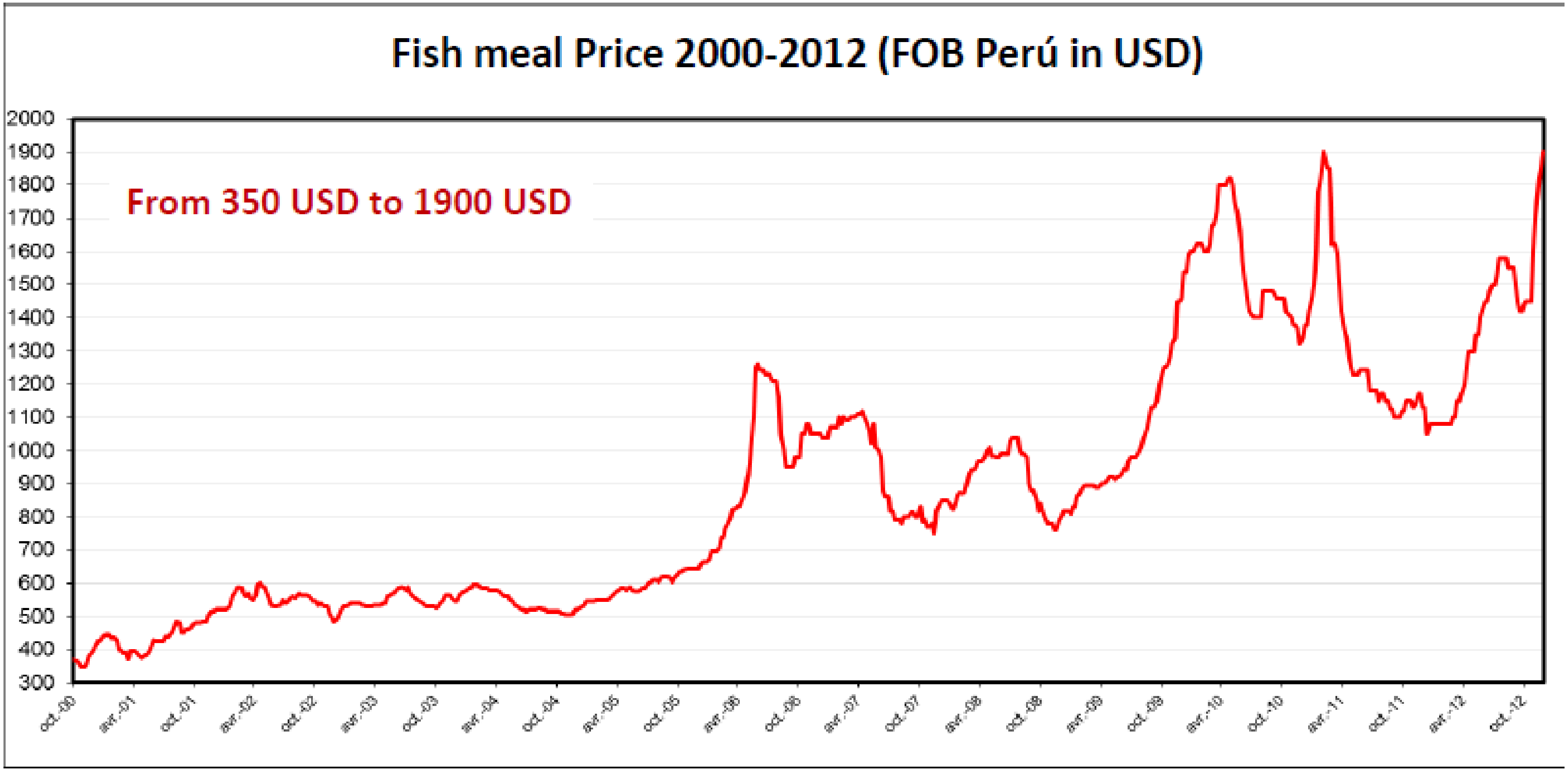
Ontario Ministry of
Natural Resources

Topic Outline

- Feed Ingredients
  - Replacement of Ingredients of Marine Origin
  - Origin and Nutritive Value of Processed Animal Proteins
- Disease Management
  - New Concepts and Novel Strategies?
  - Cataract : Possible Causes and Solutions
- Production and Feeding Management
  - Usefulness of Mathematical Nutritional Models

1. Feed Ingredients

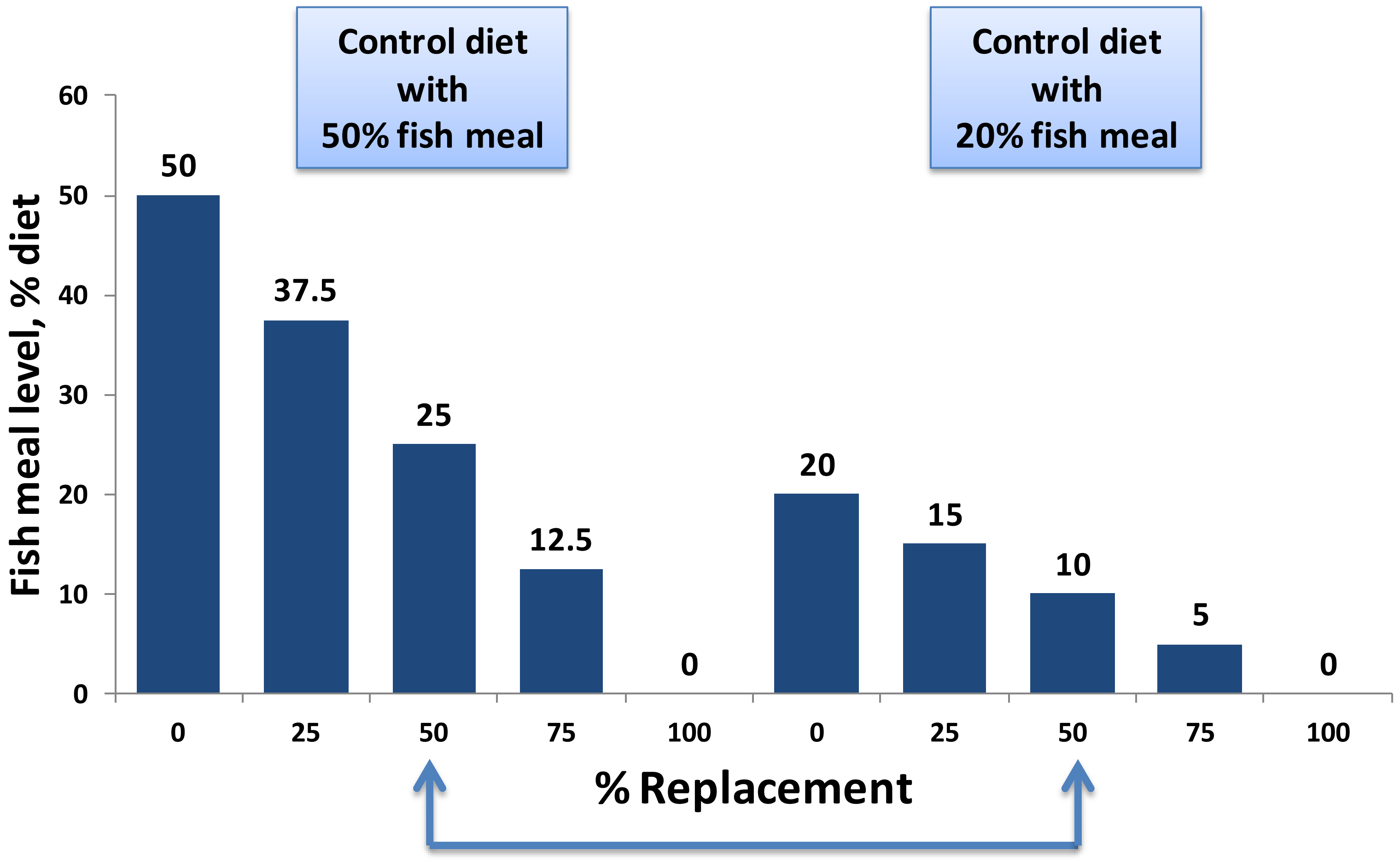
Fish Meal price evolution: aquaculture driven



"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!



Animals Utilize **NUTRIENTS**

not Proximate Components or Ingredients

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

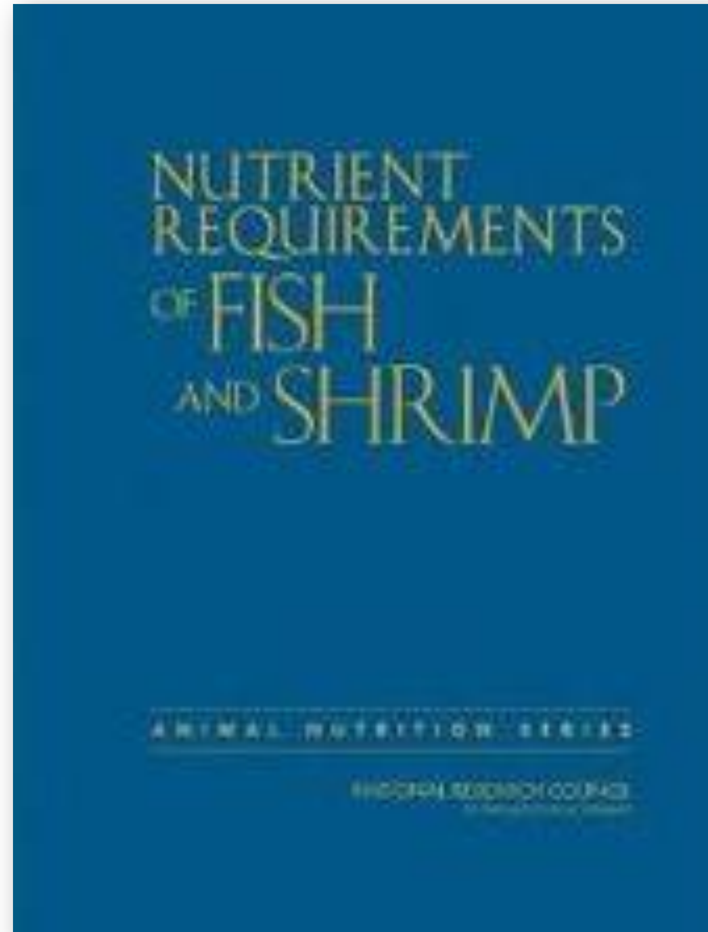
NRC Committee of Nutrient Requirements of Fish and Shrimp (2009-2011)

NRC 2011

Review of state-of-the-art

Committee reviewed 1000s of papers

Imperfect document and recommendations represent best effort



What Does Fish Meal Bring That Plant Feed Ingredients Don't?

Components/Parameters	Fish meal	Plant Proteins
Essential amino acid profile	Excellent	Excellent/Poor
Digestible amino acids	Excellent/Good	Excellent/Good
LC n-3 HUFA (EPA+DHA)	**Excellent**	**None**
LC n-6 HUFA (ARA)	**Good/Moderate**	**None**
Available phosphorus	Excellent	Moderate/Poor
Digestible energy	Good	Good/Moderate
Micro-minerals	***Excellent***	***Variable/Poor***
Phospholipids	***Excellent***	***Moderate/Poor***
Cholesterol	***Excellent***	***None***
Hormones/ Bio-active compounds	***Moderate/Low***	***Low/Moderate***
Taurine	***Excellent***	***None***
Nucleotides	***Excellent***	***Moderate/None***
Soluble fibers / Oligosaccharides	*Absent*	*Moderate/High*
Insoluble fibers (cellulose, lignin)	*Absent*	*Moderate/High*
Misc. anti-nutritional factors	***Low/absent***	***Moderate/High***
Contaminants	Moderate	Low/Moderate
Phytates	*None*	*High/Moderate*
Attractants	***High***	***Low/Moderate***

Focusing on Nutrients, not Ingredients

A simple example

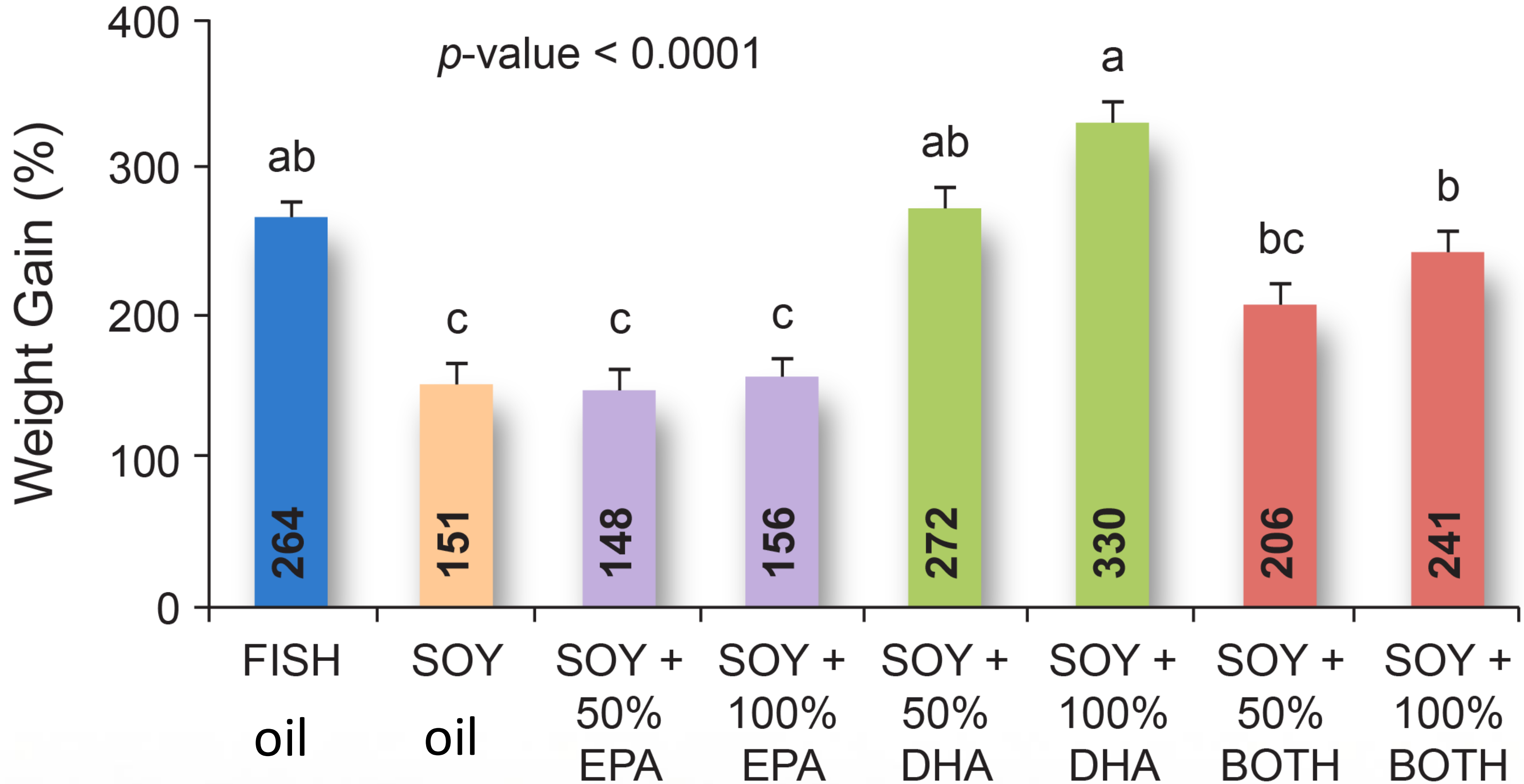
Contents lists available at SciVerse ScienceDirect

Aquaculture

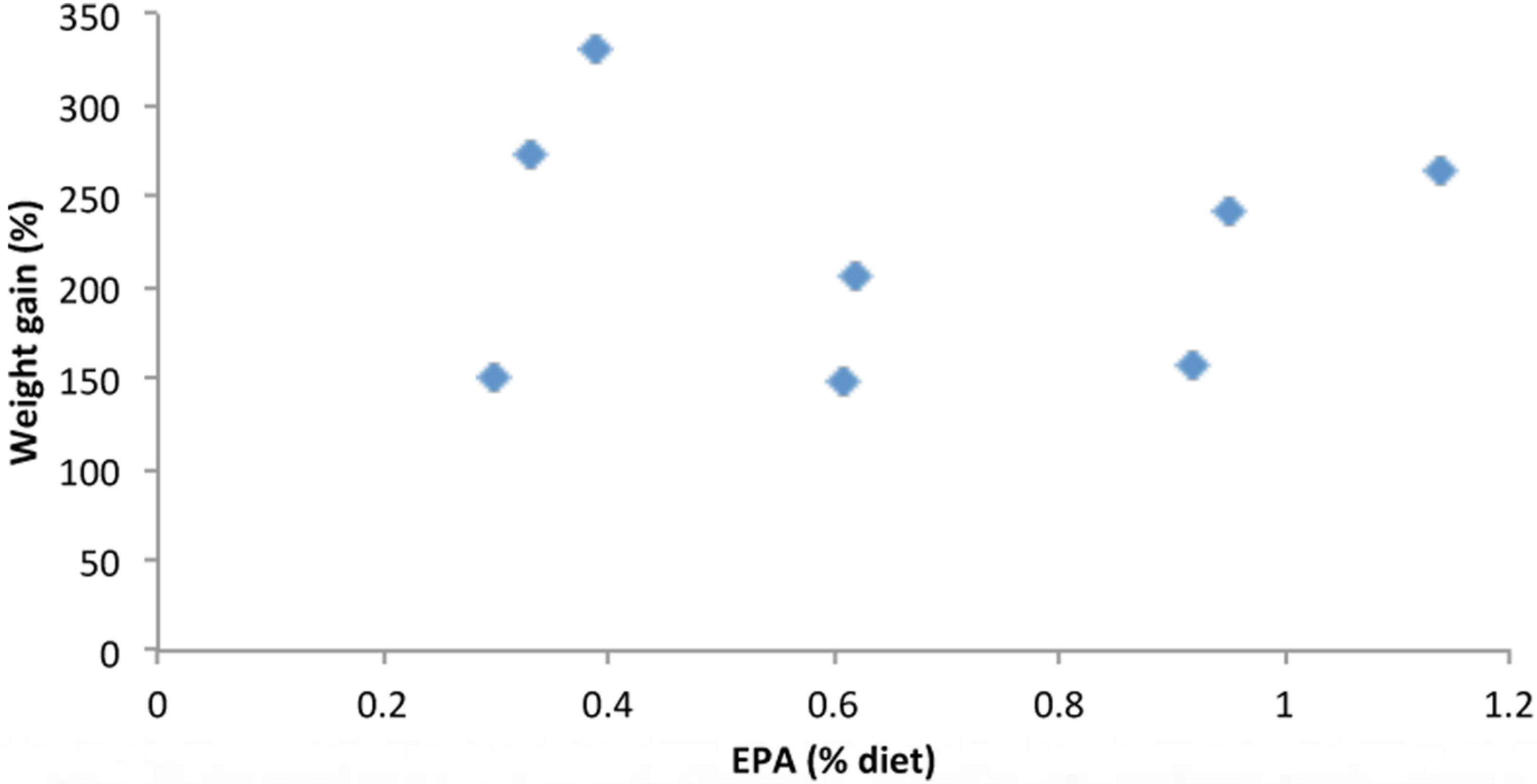
journal homepage: www.elsevier.com/locate/aqua-online

DHA is essential, EPA appears largely expendable, in meeting the n−3 long-chain polyunsaturated fatty acid requirements of juvenile cobia *Rachycentron canadum*

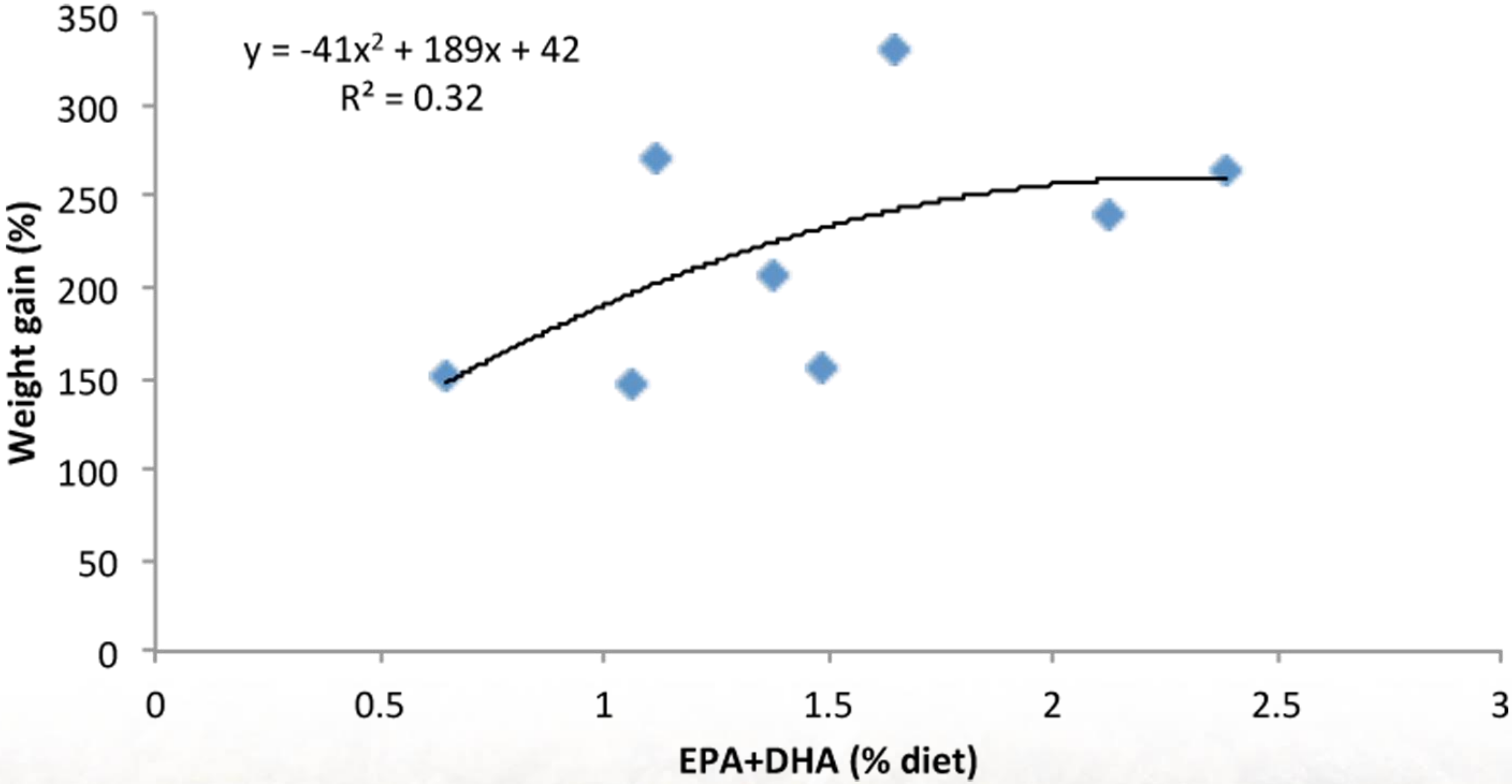
Jesse Trushenski [a,*], Michael Schwarz [b], Alexis Bergman [a,c], Artur Rombenso [d], Brendan Delbos [b]



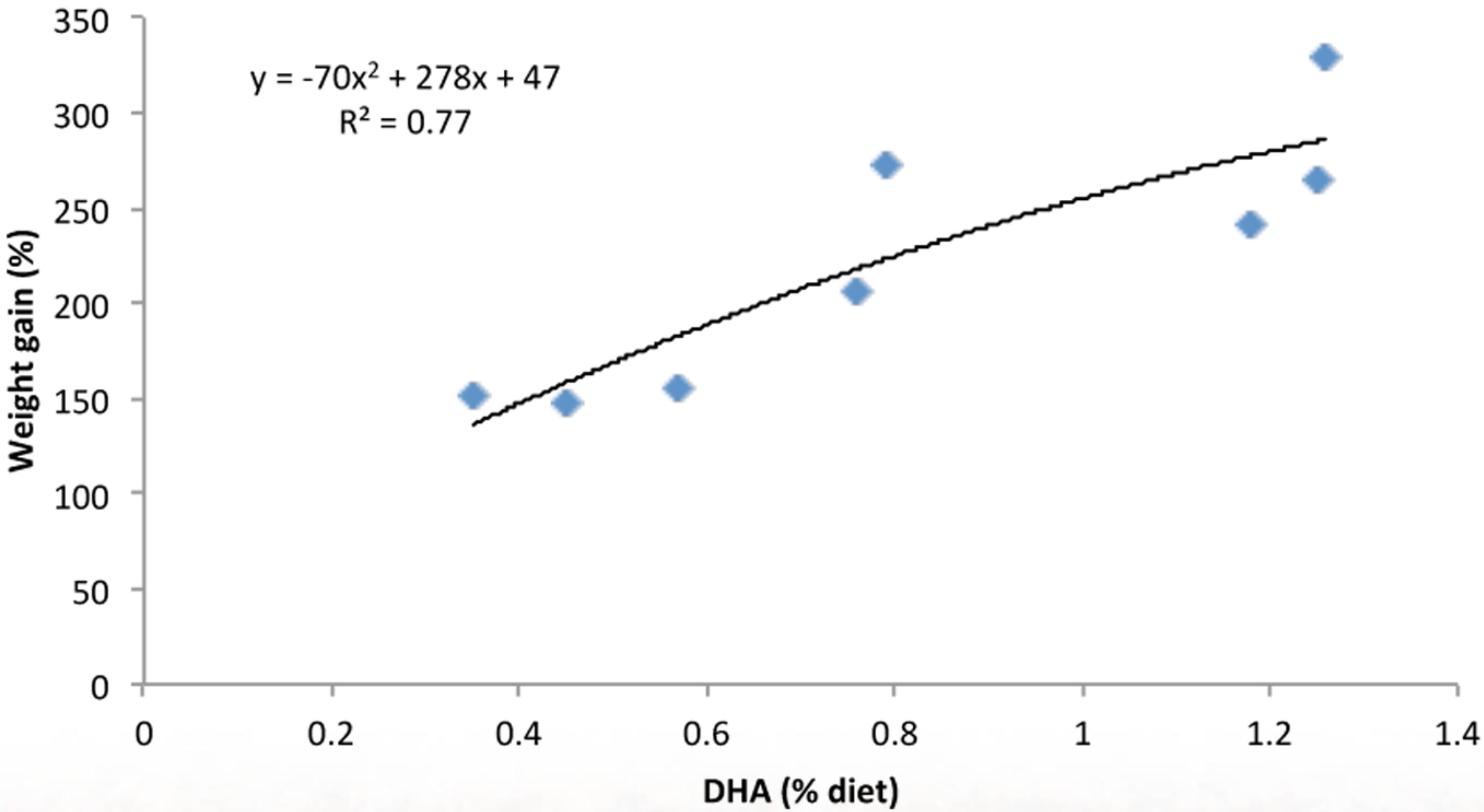
Trushenski et al. (2012)



Trushenski et al. (2012)



Trushenski et al. (2012)



Trushenski et al. (2012)

Evidence that for some species DHA is the essential fatty acid and that EPA doesn't have to same efficacy.

Table 1
Requirement of docosahexaenoic acid (DHA) and its efficacy in comparison to eicosabentaenoic acid (EPA) for larval marine fish fed on enriched *Artemia*

Species	Requirement of DHA (%)	Relative efficacy		
		Growth	Survival rate	Vitality test[a]
Japanese flounder	1.0–1.6	EPA = DHA	EPA = DHA	EPA ≦ DHA[b]
Red sea bream	1.0–1.6	EPA = DHA	EPA = DHA	EPA < DHA
Cod	1.6–2.1	EPA ≦ DHA	EPA ≦ DHA	EPA < DHA
Striped jack	1.6–2.2	EPA ≦ DHA	EPA < DHA	EPA < DHA
Yellowtail	1.4–2.6	EPA < DHA	EPA < DHA	EPA < DHA

[a] Survival at the 24th h after fish were held in air for 30–60 s by a scoop net and moved to a culture tank.
[b] Salinity tolerance test (65‰ for 120 min) was employed for flounder.

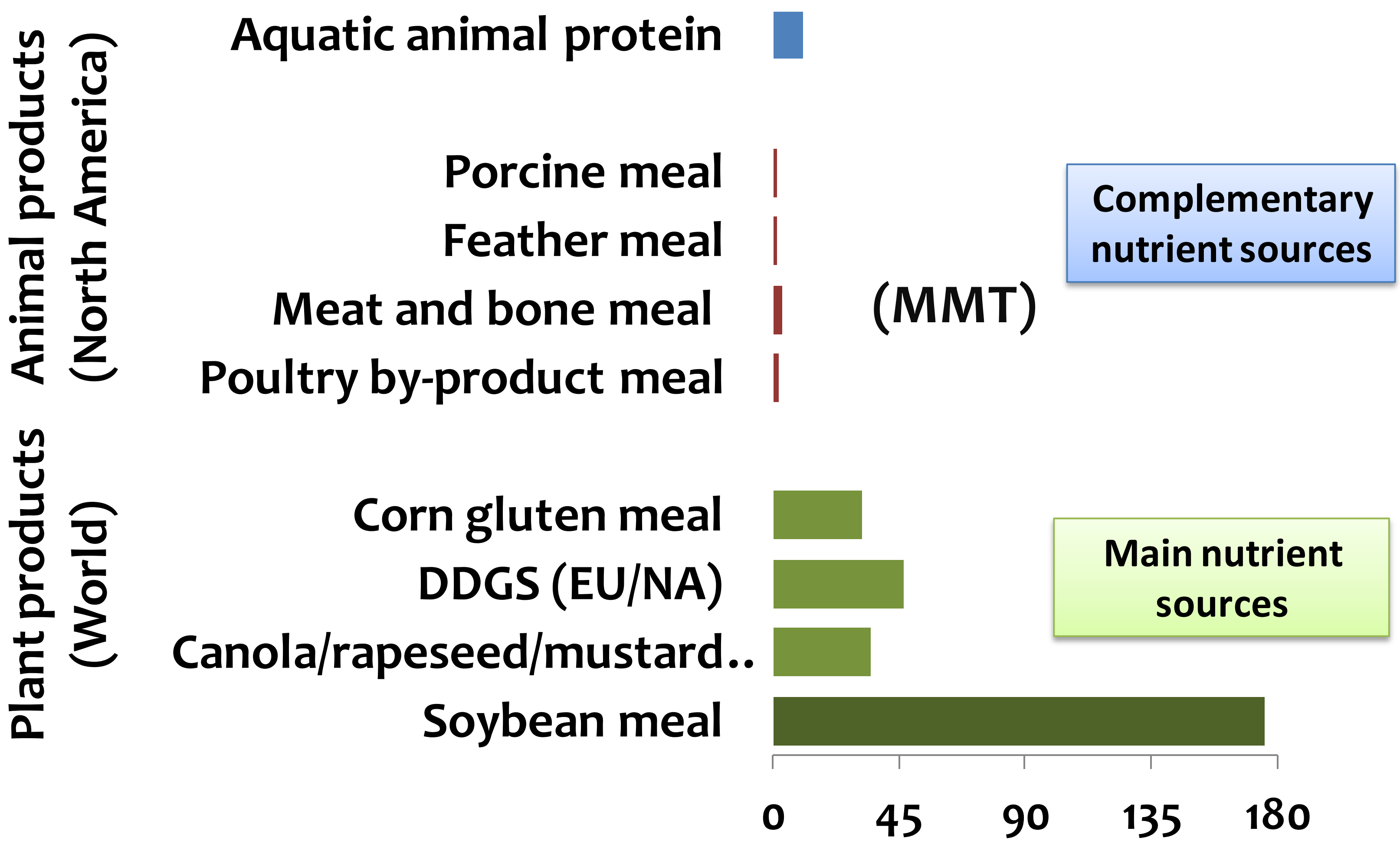
This is a lot more informative and accurate than "fish oil replacement value"

Takeuchi (2001)

What Are the Alternative Nutrient Sources?

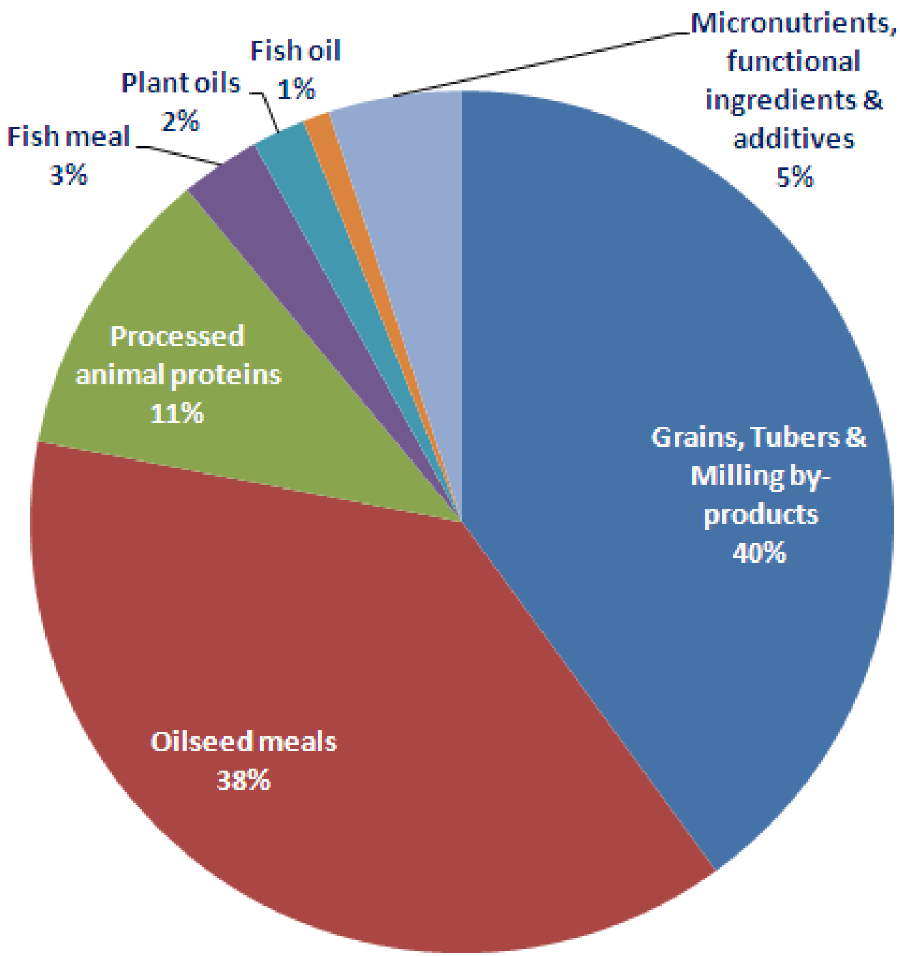
Feed Commodities :

Plant feedstuffs = Most abundant feed commodities!



Aquaculture Feed Formulation in Asia:

Complex mixtures of many different ingredients!



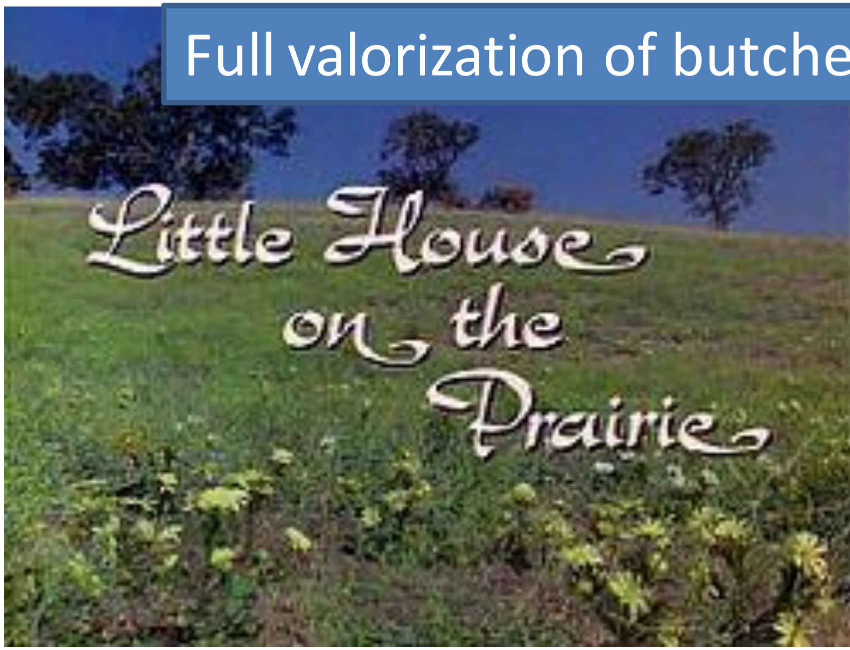
In Asia, aquaculture feeds can now be described as "plant-based feeds" with complementary use of ingredients/additives of animal and microbial origins

U.S. Animal Agriculture Annual Production

- 35 million cattle (49% of live wt. not used for human food)
- 100 million hogs (44% not used for human food) **“Eating high off the hog”**
- 8 billion chickens (37% not used for human food)
- 280 million turkeys (36% not used for human food)

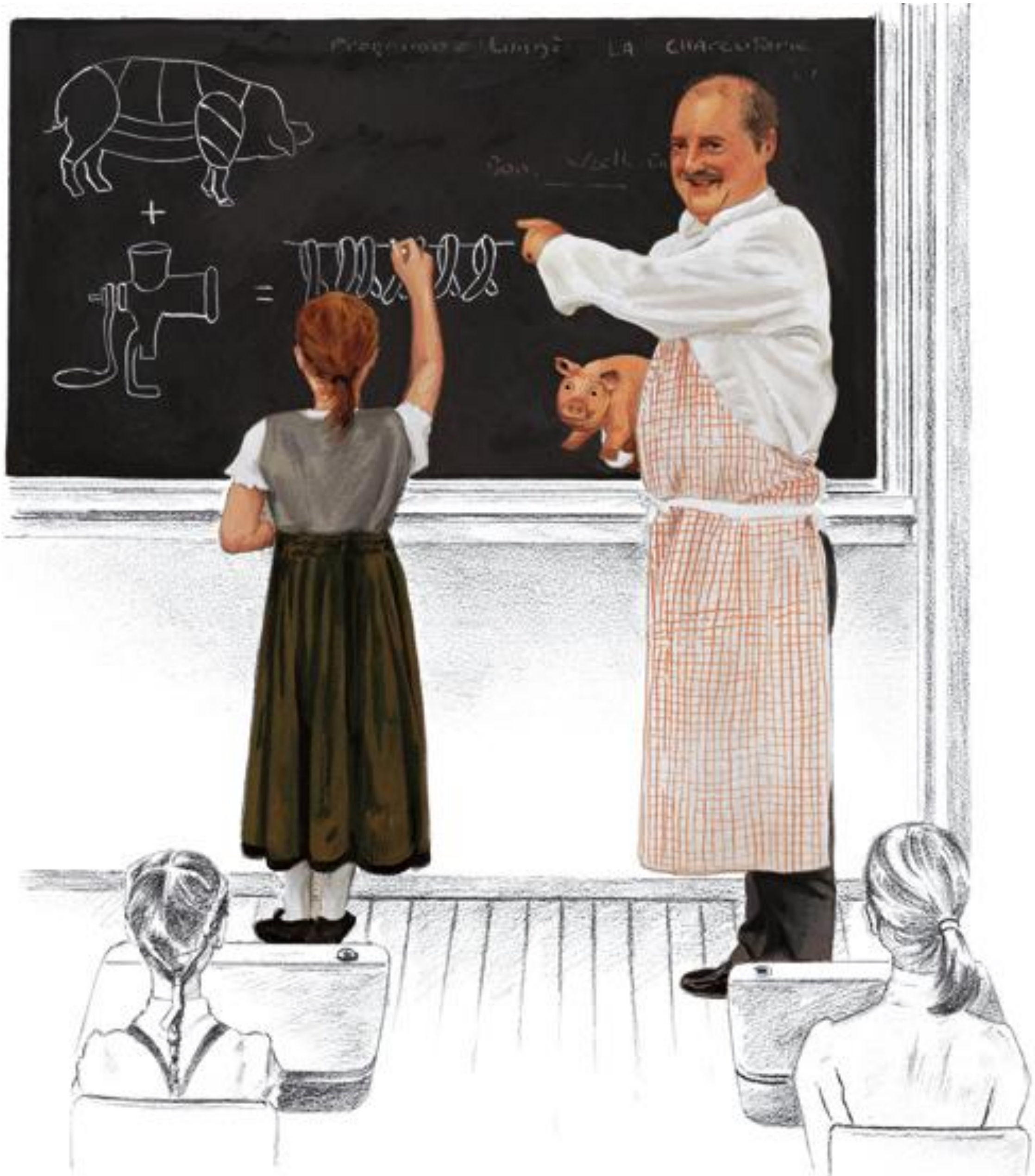



Full valorization of butchered animals in an agrarian society



"When butchering time was over, there were the sausages and the headcheese, the big jars of lard and the keg of white salt-pork out in the shed, and in the attic hung the smoked hams and shoulders."

(Laura Ingalls Wilder. 1932. Little House in the Big Woods)



Michel Charvet
Salaisons d'Alsace

Dans le cochon, tout est bon!

En el cerdo, todo es bueno

Delicatessen ("Charcuterie") Counter in Europe

Gastronomical Treasures…

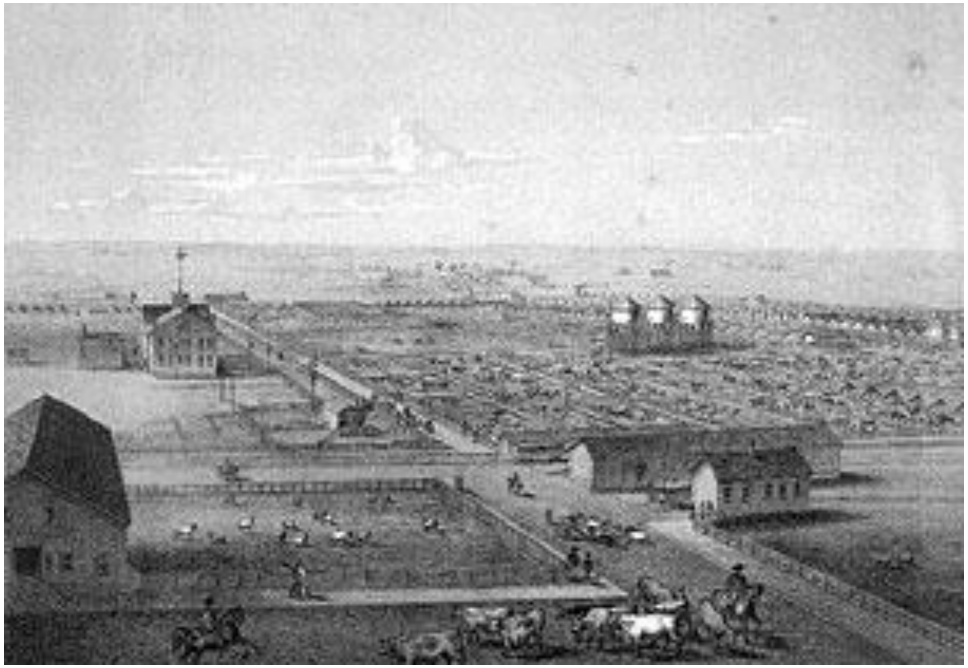
Salade de gésiers
(Gizzard salad)
France

Tripes à la mode de Caen
(Caen-style tripes)
France

Tkalia ou Douara
(Lamb offals stew)
Morocco

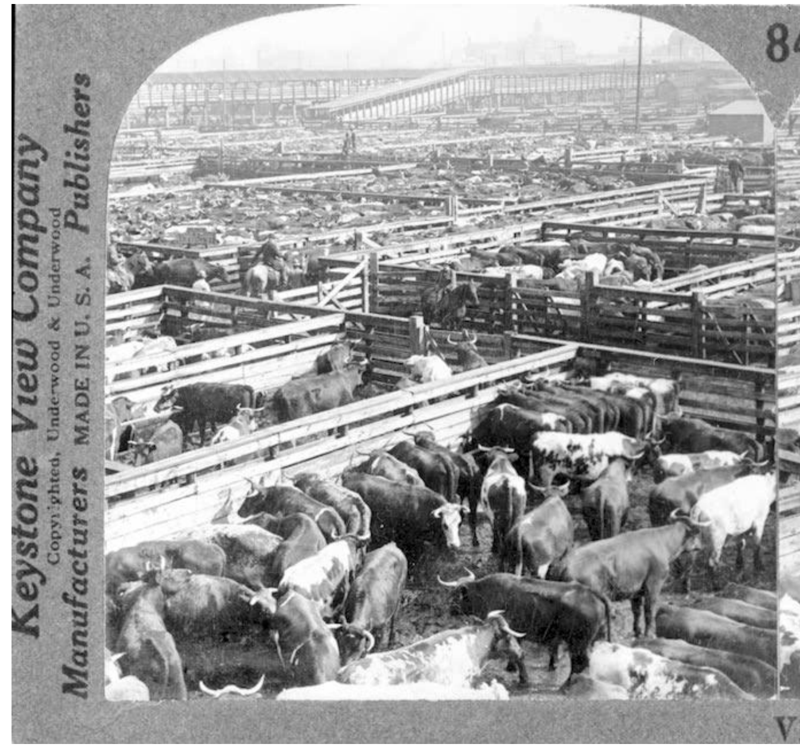
Chicken feet dim sum
China

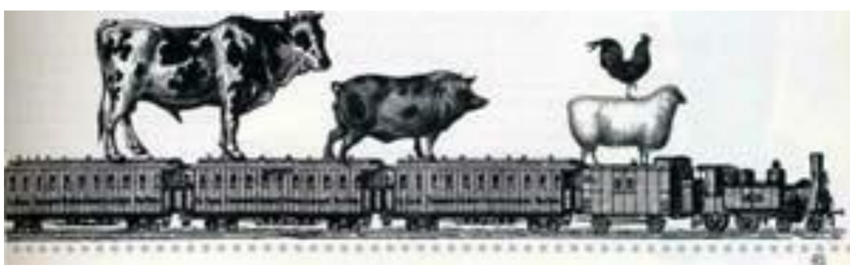
Centralization of Meat Packing Facilities



Union Stock Yards, 1866. (CHS ICHi-06898)

Chicago stockyards, ca. 1913.





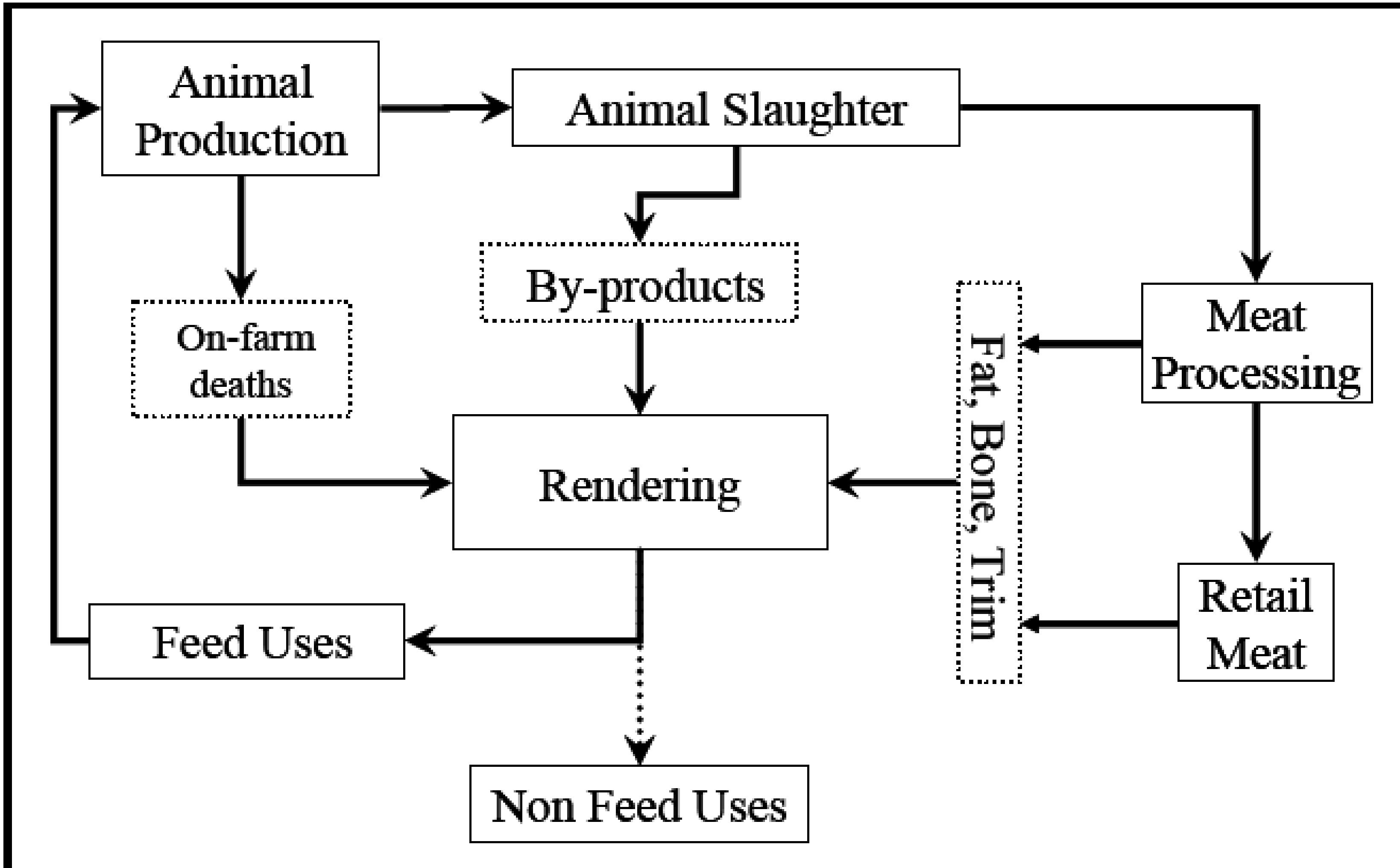
"Five hundred animal pens covering 60 acres of land were used to house the livestock, and the whole operation could accommodate 21,000 head of cattle, 75,000 hogs, 22,000 sheep, and 200 horses at one time,"

A Potential Environmental Disaster


Without rendering, all available space in landfills would be used within 4 years
Rendering Is Recycling!   www.nationalrenderers.org

Sustainable Agriculture Systems

Figure 1. Interrelationships of Rendering with Animal Agriculture.



The Rendering Industry (U.S. and Canada)

- 273 facilities in the U.S. and 29 in Canada
- $3.5 billion annual revenue
- 26.3 MMT (59 billion lb) raw material each year
- 72.3 million kg raw material each day

Raw Materials

- Offals
- Bones and fat
- Blood
- Restaurant grease
- Feathers
- Recalled meat

Examples of a Few Finished Products

Stabilized Poultry Fat

Hydrolyzed Poultry Feather Meal

Stabilized Pet Food Poultry Fat

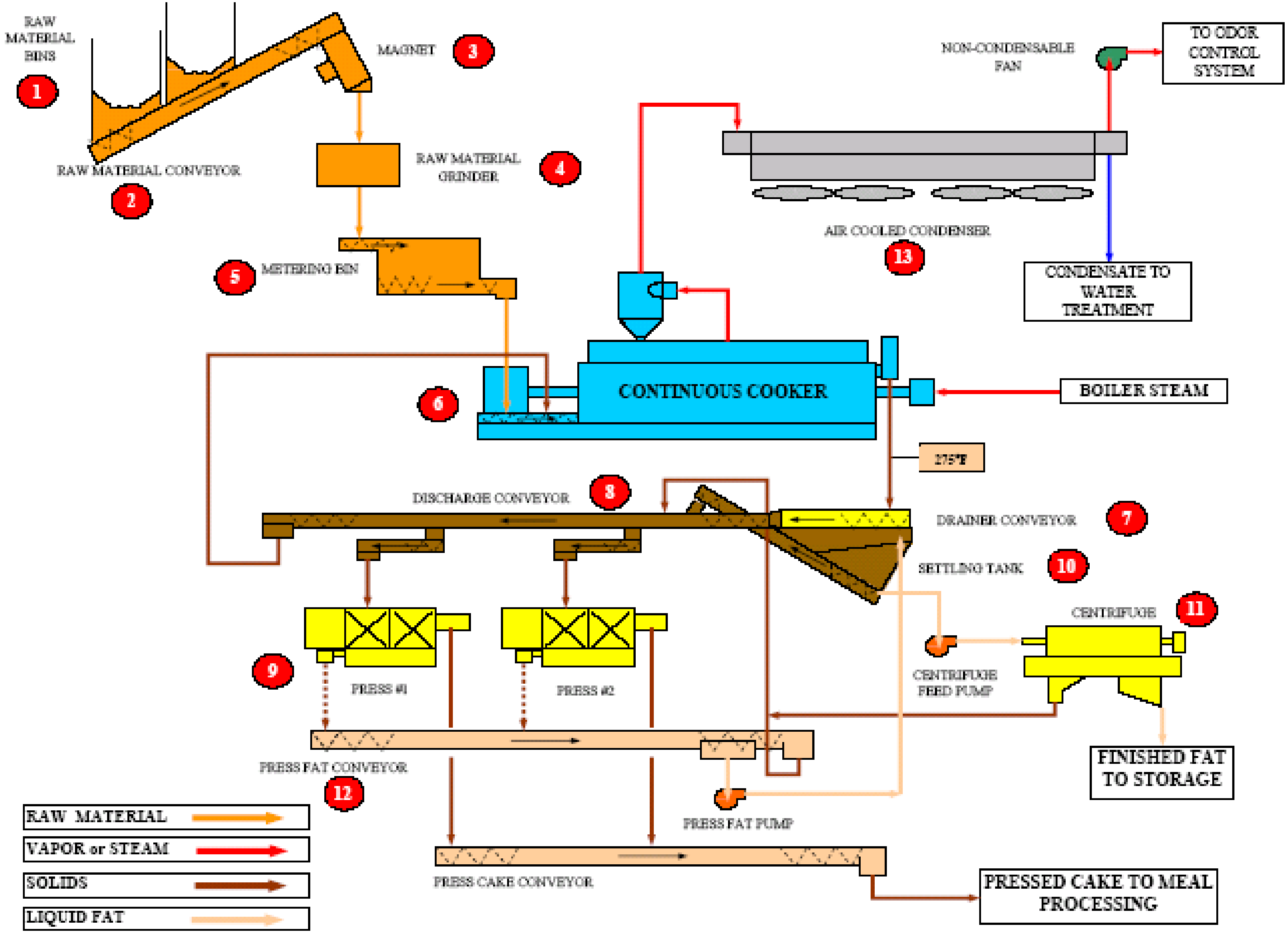
Stabilized Poultry Protein Meal

Low Ash Pet Food Poultry Protein Meal

Pet Food Poultry Protein Meal

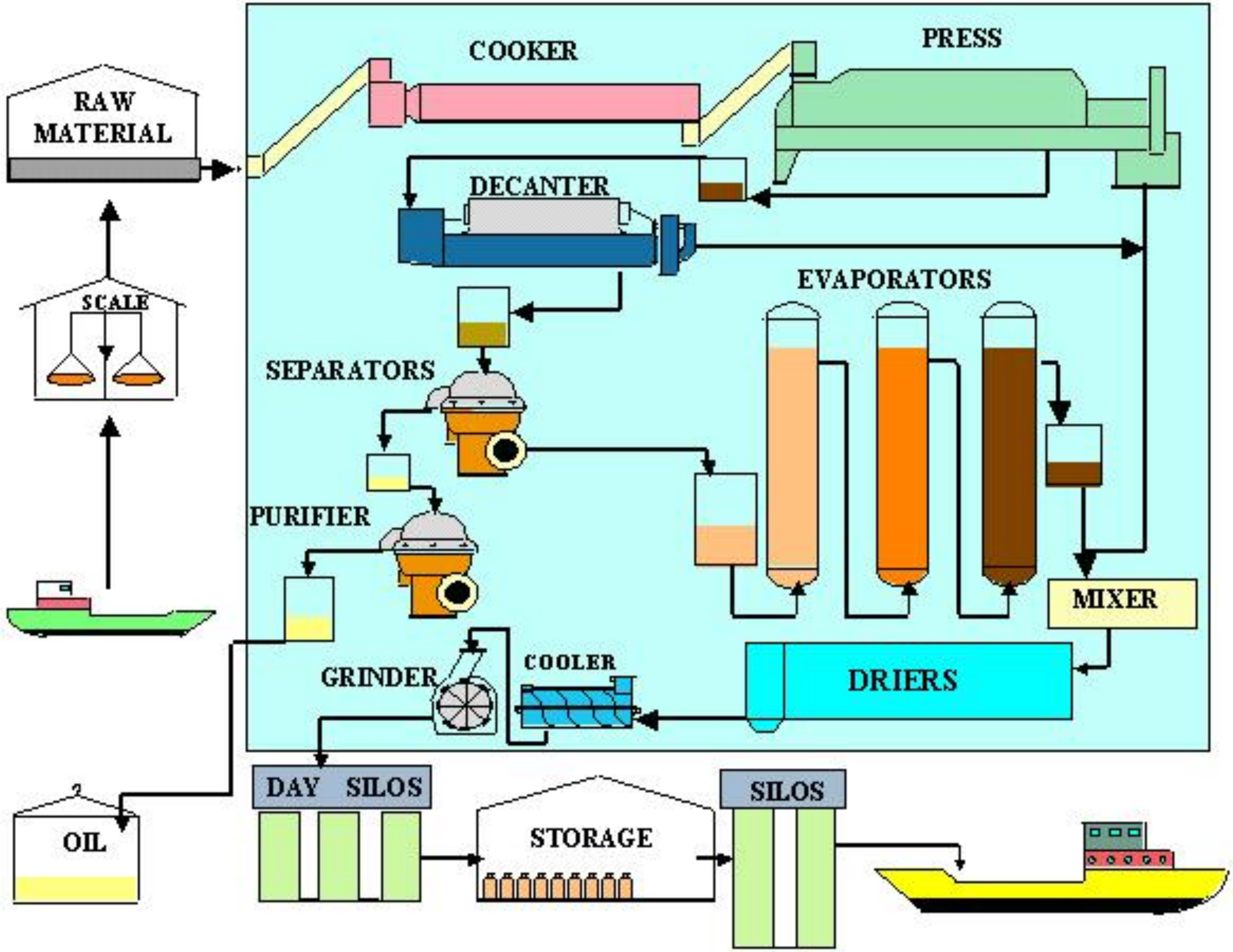
Rendering is Cooking and Drying

- Continuous flow or batch
- Steam cookers
- 115º to 145º C. for 40 to 90 minutes (245º to 290º F.)
- Rendering offers a sanitary and eco-friendly way to dispose of the massive amount of meat and food by-products produced every year.
- Such materials spoil easily and make an excellent media for pathogens to grow and multiply.
- Temperatures used during processing kill conventional disease-causing organisms, such as bacteria and viruses.



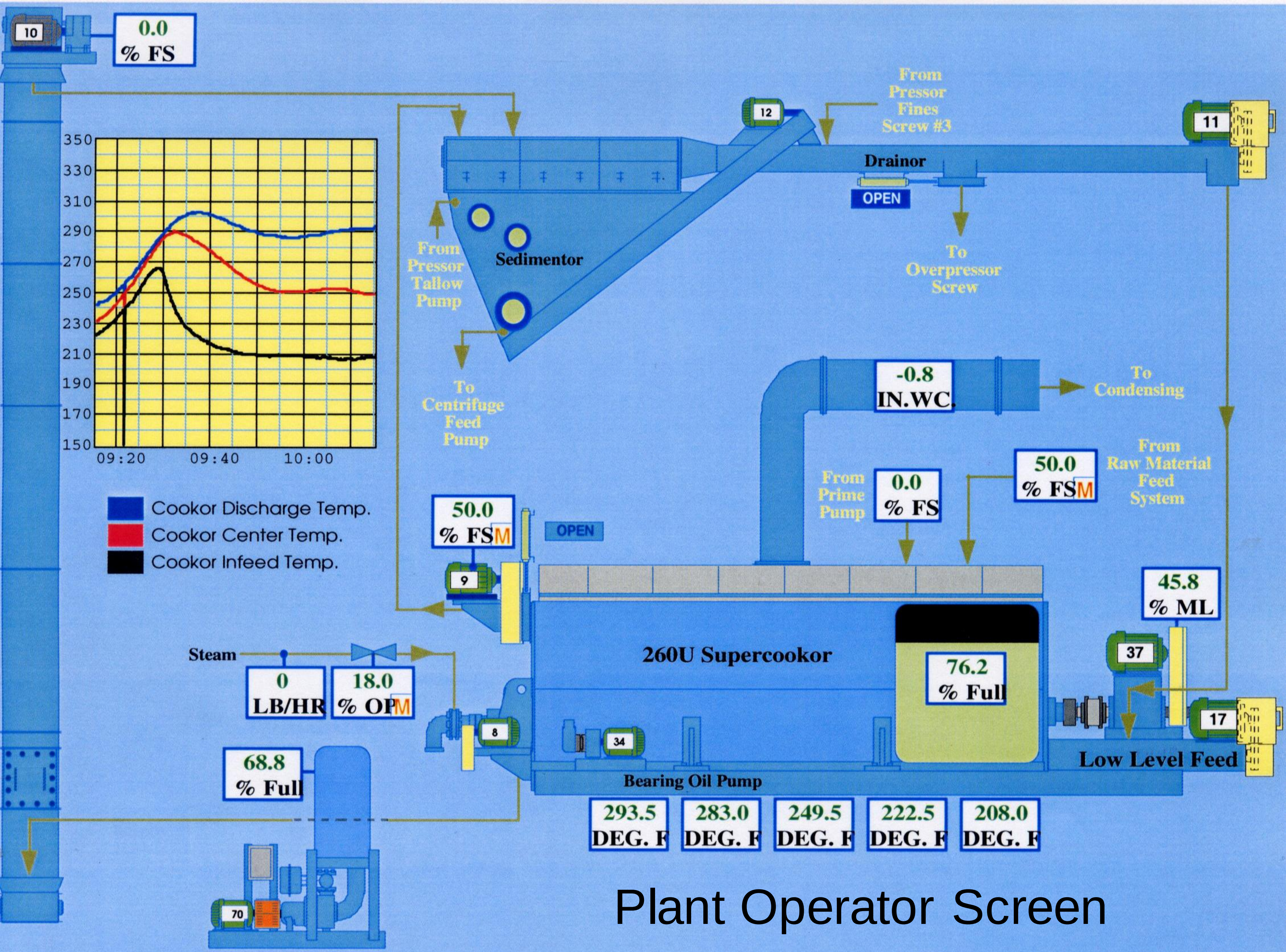
CONTINUOUS SYSTEM

Fish Meal and Fish Oil Production Plant



Process Controls in Rendering

Cooking temperature, time and other conditions (loading, pressure/vacuum, moisture levels, etc.) are closely monitored, controlled, and recorded.



Plant Operator Screen

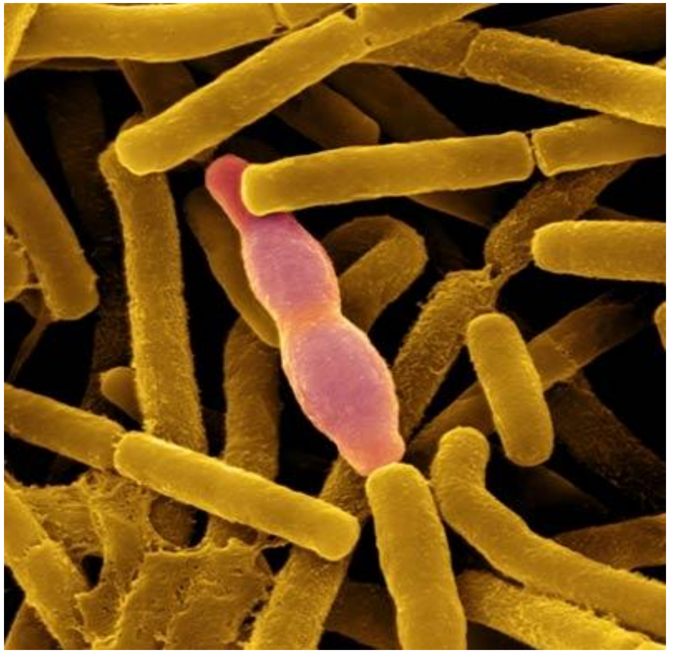
Rendering Destroys Bacteria of Food Safety Concern

Bacteria	Raw Tissue	Post-Press
Clostridium perfingens	71%	0%
Listeria species	76%	0%
L. Monocytogenes	8%	0%
Campylobacter species	30%	0%
C. Jejuni	20%	0%
Salmonella species	85%	0%

U. Of Illinois, 2001. 17 rendering facilities sampled summer and winter.
Percentage of samples having pathogens present.

Rendering Inactivates Organisms Important to Human and Animal Health

- Foot-and-Mouth Disease (FMD)
- Pseudorabies Virus (PRV)
- Bacillus Anthracis (Anthrax)
- Avian Influenza



Bacillus Anthracis cells with spores

Adequately Characterizing the Chemical Composition and Nutritive Value of Ingredients

Historical Note (1995)

1970-95 : Review of literature and discussions with feed industry personnel and researchers indicate general lack of trust in nutritive value of animal proteins for fish

Why?

Digestibility values of certain animal products reported in the reference literature (up to 1993) were very low, making these ingredients uninteresting to use.

USA National Research Council (1993):

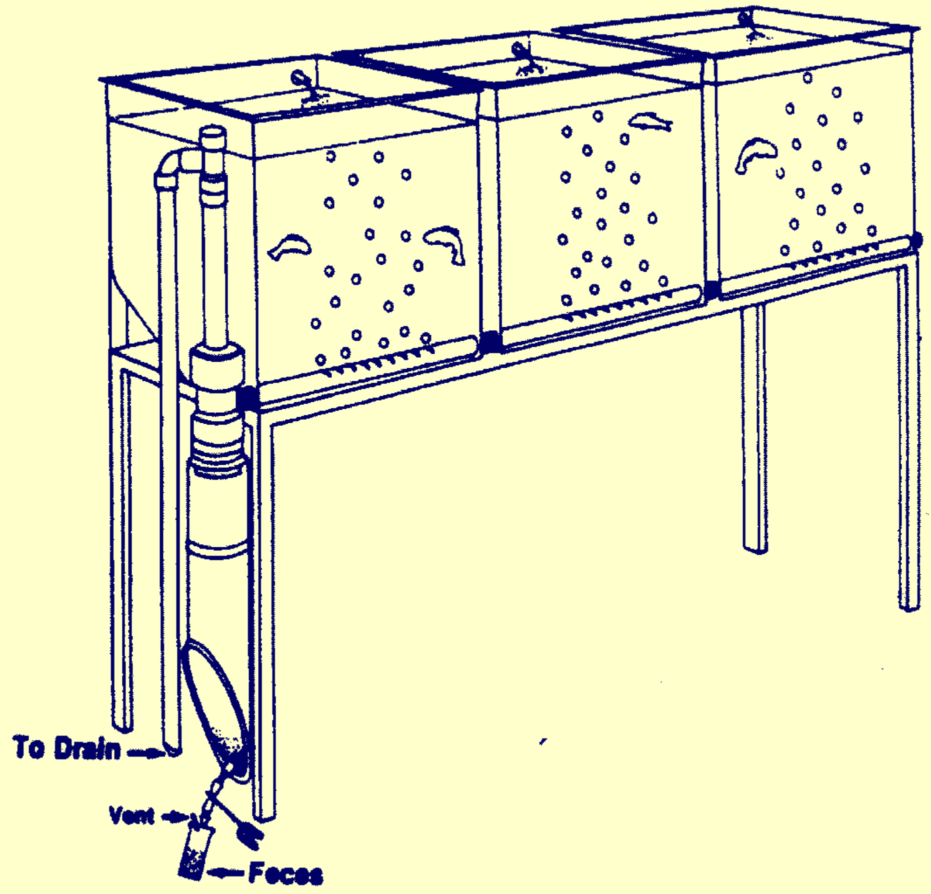
Apparent digestibility coefficient (ADC) of protein

Feather meal	58%
Poultry meal	68%

Data from
Cho & Slinger (1979)
(U of Guelph)

Are these old Guelph reference values realistic?

The Guelph System (Cho et al., 1982)



Collection of Fecal Samples

Apparent Digestibility of Feather Meals

	ADC	
Guelph System	**Protein**	**Energy**
Cho et al. (1982)	58%	70%
Sugiura et al. (1998)	82-84%	N/A
Bureau (1999)	81-87%	76-80%
Stripping	HCl hydrolyzed feather meal	
Pfeffer et al. (1995)	83%	81%

Data obtained using the same facilities and methodology. There is value in using standard methodological approaches consistently over many years.

Apparent Digestibility of Poultry By-Products Meal

Guelph System	ADC Protein	ADC Energy
Cho et al. (1982)	68%	71%
Hajen et al. (1993)	74-85%	65-72%
Sugiura et al. (1998)	96%	N/A
Bureau et al. (1999)	87-91%	77-92%

Data obtained using the same facilities and methodology

FNRL

Meat and Bone Meal

	ADC	
Guelph System	**Protein**	**Energy**
Cho et al. (1982)	62%	70%
Bureau et al. (1999)	83-89%	68-82%
Stripping		
Skrede et al. (1980)	59%	N/A
Dimes et al. (1994)	70%	N/A

Apparent Digestibility of Processed Animal Proteins in the late 1990s

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
Trial #2			
Meat and bone meal 3	72	88	82
Meat and bone meal 4	66	87	76
Meat and bone meal 5	70	88	82
Meat and bone meal 6	70	89	83
Trial #3			
Feather meal 5	86	88	84
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

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

Fish meal is not fish meal and poultry by-products meal is not poultry by-products meal. These are generic names that regroup ingredients that can be widely different.

Cheng and Hardy (2002)

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

Information on EAA content and digestibility is extremely meaningful
for the formulation of cost-effective feeds

Cheng and Hardy (2002)

ENRL

Use of Rendered Animal Proteins in Practical Feeds

Formulation of Experimental Diets Used in Feather Meal Trial

Ingredients	Diet							
	1	2	3	4	5	6	7	8
Herring meal	50	35	35	35	50	40	30	20
Blood meal, tube-dried	10	10	10	10	6	9	12	15
Feather meal 1		15						
Feather meal 2			15					
Feather meal 4				15	8	12	16	20
Corn gluten meal	10	10	10	10	6	9	12	15
Whey	12	12	12	12	12	12	12	12
Vitamins + minerals	3	3	3	3	3	3	3	3
Fish oil	15	15	15	15	15	15	15	15

Performance of rainbow trout fed diets with different feather meals

Diet	Gain g/fish	Feed g/fish	FE G:F	RN g/fish	RE kJ/fish
1- Control	73.5 ab	51.6	1.42 ab	1.9 a	587 a
2- 15% FEM 1	74.3 ab	51.4	1.44 a	1.9 a	553 a
3- 15% FEM 2	71.1 bc	52.0	1.37 bc	1.8 a	561 a
4- 15% FEM 4	73.0 abc	52.3	1.40 abc	1.9 a	547 a
5- 20% FEM-CGM-BM	74.5 a	51.8	1.44 a	1.9 a	574 a
6- 30% FEM-CGM-BM	73.2 abc	51.7	1.42 abc	1.9 a	554 a
7- 40% FEM-CGM-BM	73.3 abc	52.2	1.41 abc	1.9 a	579a
8- 50% FEM-CGM-BM	70.1 c	51.8	1.35 c	1.8 a	537a

Could not highlight differences in the nutritive value of feather meals with different digestible protein levels. Diets 2-4 contained at least 35% fish meal.

Experimental Diets for Protein Combination Trial

Ingredients	Diet							
	1	2	3	4	5	6	7	8
Fish meal , herring	40	20	20	20	20	20	20	20
Soybean meal, 48% CP	13	-	-	-	-	-	-	-
Wheat middling	5	-	-	-	8	8	8	-
Corn gluten meal, 60% CP	11	11	11	11	11	11	11	11
Whey	9.5	6	6	6	6	6	6	6.5
Blood meal, spray-dried	4.5	5	4.5	4.5	5	4.5	4.5	5.5
Meat-bone meal 50%CP	-	25	25	25	-	-	-	25
Poultry by-products meal	-	-	-	-	16	16	16	16
Feather meal, 77% CP	-	17	17	17	17	17	17	-
L-Lysine HCL	-	-	-	0.5	-	-	0.5	-
DL-Methionine	-	-	0.5	-	-	0.5	-	-
Vit.+ min. premix	3	3	3	3	3	3	3	3
Fish oil, herring	14	13	13	13	14	14	14	13
Calculated composition (dry matter basis)								
Digestible protein (DP), %	42.2	42.1	42.2	42.2	42.2	42.3	42.3	42.2
Digestible energy (DE), MJ/kg	19.1	19	19	19	18.9	19	19	19.1
DP:DE, g/MJ	22.1	22.2	22.2	22.2	22.2	22.3	22.3	22.1

Fish Performance in Protein Combinations Trial

Diet	Final Weight g/fish	Feed Efficiency G:F	TGC*
1- Control	278 a	1.19 a	0.261 a
2- FEM + MBM	247 bcd	1.04 bc	0.241 bc
3- FEM+MBM+Met	248 bcd	1.06 bc	0.241 bc
4- FEM+MBM+Lys	242 d	1.03 c	0.238 c
5- FEM+PBM	264 ab	1.14 ab	0.252 ab
6- FEM+PBM+Met	251 bcd	1.06 bc	0.243 bc
7- FEM+PBM+Lys	261 abc	1.11 abc	0.250 abc
8- MBM+PBM	245 cd	1.04 c	0.239 bc

Duration = 12 weeks **Initial weight = 35 g/fish** **Temperature = 15 ^{o}C**

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

Experimental Diets in Poultry By-Products Meal and Blood Meal Trial

Ingredients	Diet				
	1	2	3	4	5
Fish meal , herring	28	24.5	28	24	20
Corn gluten meal	28	24.5	28	24	20
Wheat middling	5	5	-	-	-
Blood meal, spray-dried	6	12	-	-	-
Poultry by-product meal	-	-	10	20	30
Whey	10	10	11	9	7
CaHPO4	0.5	0.5	0.5	0.5	0.5
L-Lysine HCL	1	0.8	1	1	1
Arginine	-	0.2	-	-	-
Vit.+ min. premix	3.5	3.5	3.5	3.5	3.5
Fish oil	18	19	18	18	18
Calculated composition (dry matter basis)					
Digestible protein (DP), %	41.2	41.6	41.4	41.7	41.1
Digestible energy (DE), MJ/kg	20.1	20.4	20.5	20.5	20.5
DP:DE, g/MJ	20.5	20.4	20.2	20.4	20.5

Performance in Poultry By-Products Meal & Blood Meal Trial

Diet	FBW g/fish	TGC	FE G:F	ADC Protein	ADC Energy
1- Control 6% BM	209	0.200	1.11	96	92
2- 12% BM	215	0.205	1.19	95	91
3- 10% PBM	201	0.195	1.11	95	93
4- 20% PBM	202	0.199	1.13	94	92
5- 30% PBM	209	0.199	1.13	93	92

No significant difference according to Tukey's HSD test.

Initial body weight = 17 g/fish, Duration= 16 weeks, Temp. = 15 °C

Feeds Based on Herring Meal, Menhaden Meal or Poultry Meal

	1	2	3	4	5	6
Ingredients	**MM10**	**MM20**	**HM10**	**HM20**	**NFM**	**Profishent**
Fish meal, herring	-	-	100	200	-	+
Fish meal, menhaden	100	200	-	-	-	-
Poultry by-prod. meal	300	200	300	200	400	+
Soybean meal	90	80	120	120	70	+
Corn gluten meal	150	150	120	90	150	+
Feather meal	50	70	50	70	70	+
Wheat	100	100	110	130	100	+
Fish oil, herring	120	110	120	110	130	+
Poultry Fat	60	60	60	60	50	+

Unit: kg/tonne of feed

Growth and Feed Efficiency of Rainbow Trout Fed the Test Feeds for 16 weeks at 15ºC.

Diet	Initial weight (g/fish)	Final weight (g/fish)	Weight gain (g/fish)	Feed intake (g/fish)	FE (gain/feed intake)	TGC (%)
MM10	15.5	205	189.2	180.1	1.05^{b}	0.199
MM20	15.5	193	177.3	158.4	1.12^{ab}	0.192
HM10	15.4	203	187.5	161.0	1.16^{ab}	0.199
HM20	15.8	222	206.4	171.7	1.20^{a}	0.208
NFM	16.0	208	192.1	182.2	1.06^{b}	0.199
Profishent	15.9	203	187.5	165.3	1.13^{ab}	0.197
SEM		6.2	6,2	5.2	0.03	0.03

[1] Values with different subscript letters are significantly different ($P<0.05$)

Effect of dietary ratio of fish meal to poultry by-product meal on growth, feed utilization and waste output of Japanese sea bass (*Lateolabrax japonicus*)

Fei Wang[a,b], Yan Wang[a*], Wen-Xiu Ji[a], Xu-Zhou Ma[b]

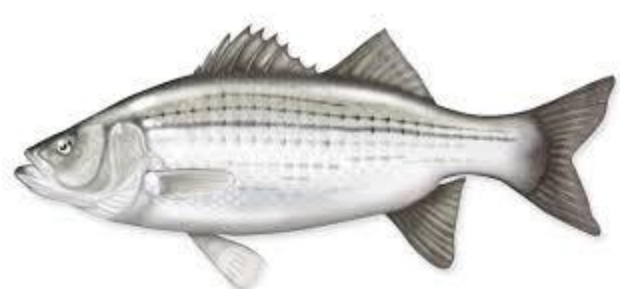
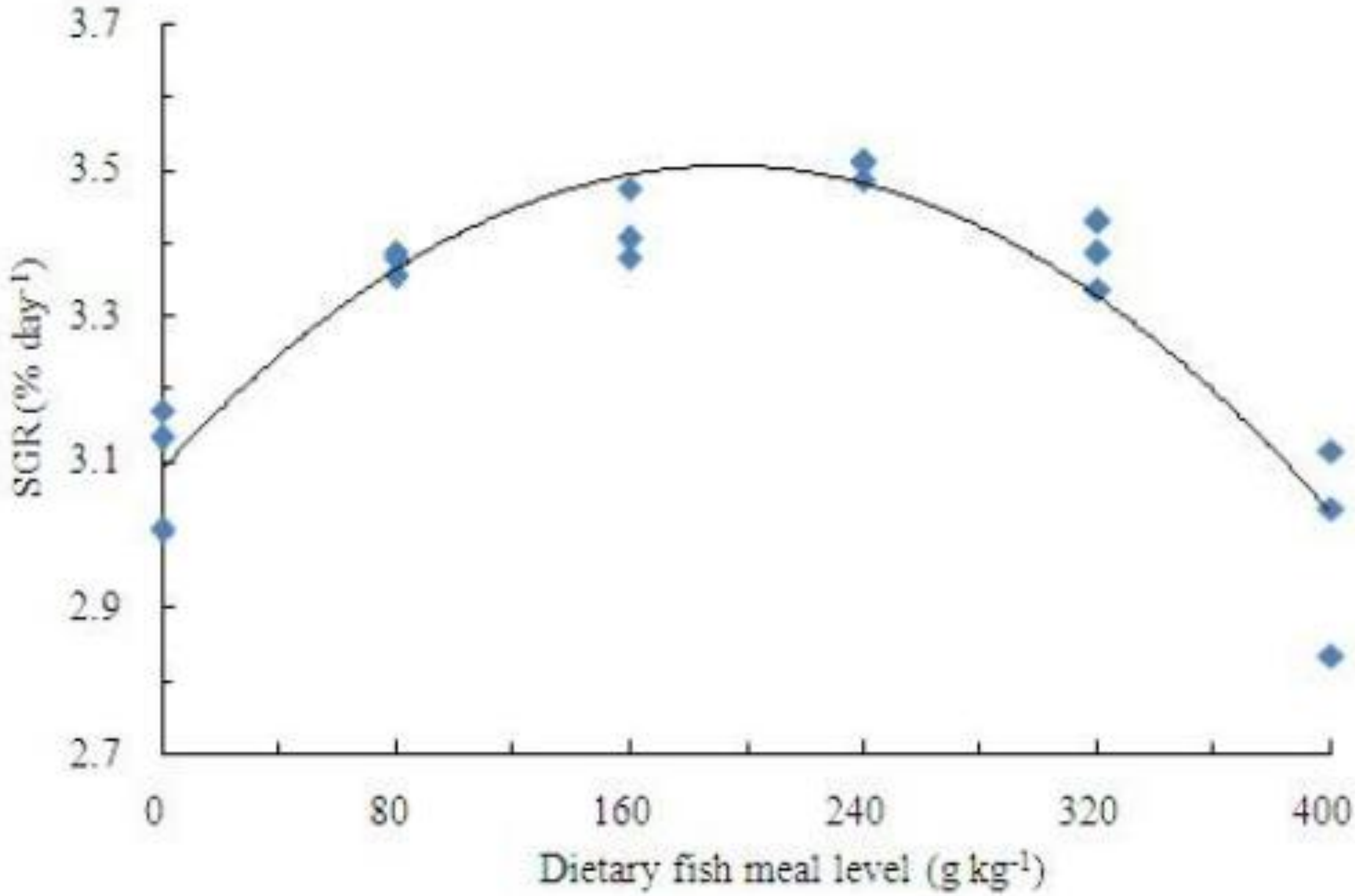
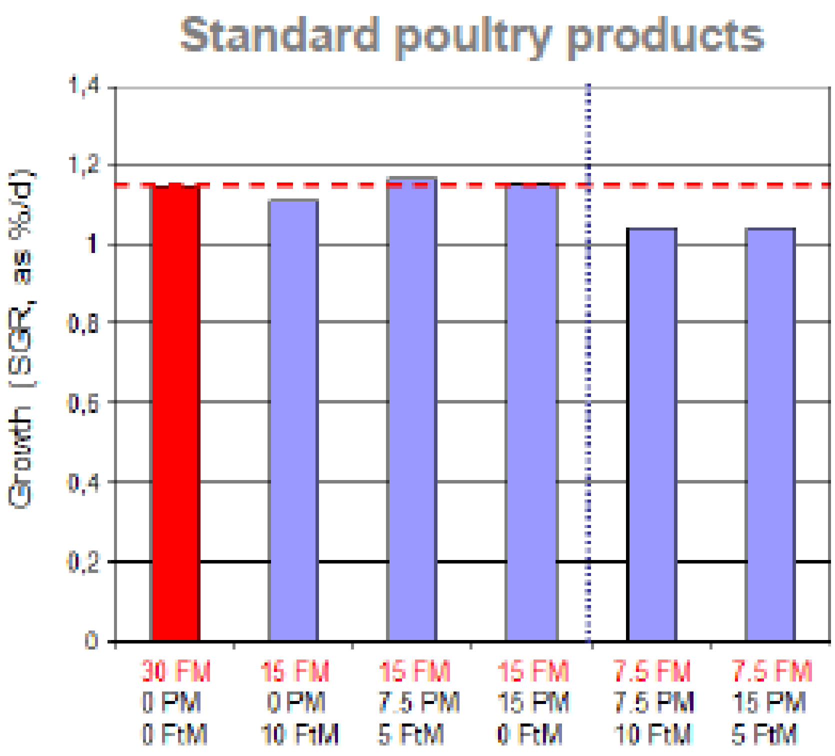


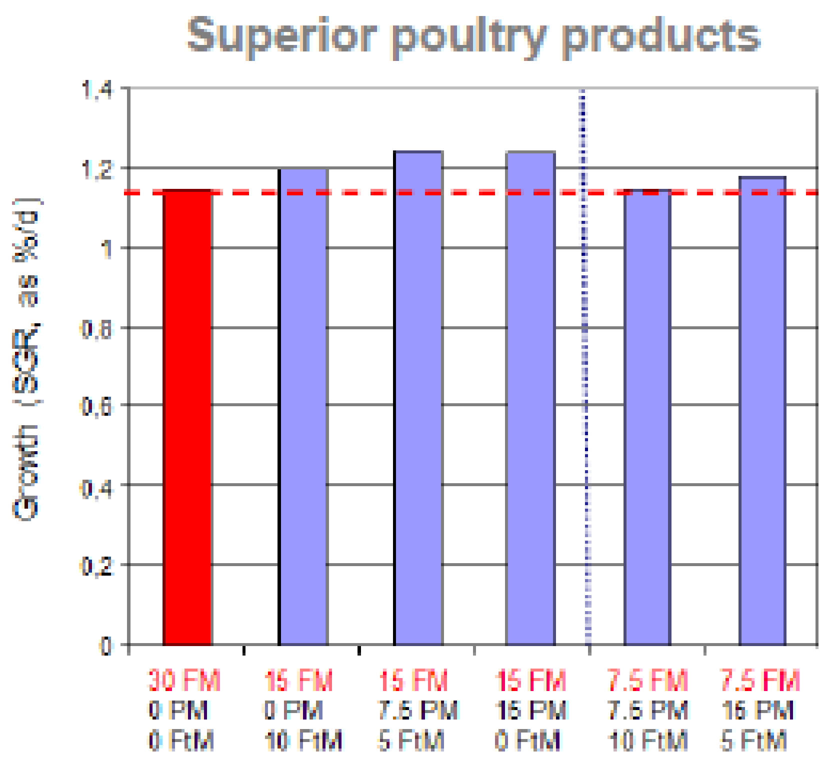
Table 2 Formulation (g kg^{-1}), proximate composition (g kg^{-1}) and energy content (MJ kg^{-1}) of the test diets

Ingredient	C	PM1	PM2	PM3	PM4	PM5
Fish meal	400	320	240	160	80	0
Poultry by-product meal	0	97	194	291	387	482
Rapeseed meal	80	80	80	80	80	80
Soybean meal	200	200	200	200	200	199
Brewer's yeast	30	30	30	30	30	30
Starch, gel.	20	20	20	20	20	20
Wheat flour	165	153	142	132	120	112
$CaHPO_4$	10	10	10	10	10	10
DL-Met	5	7	6	6	8	8
Vitamin premix	10	10	10	10	10	10
Mineral premix	10	10	10	10	10	10
Fish oil	70	63	58	52	46	40


3.7
3.5
3.3
3.1
2.9
2.7
SGR (% day-1)
0
80
160
240
320
400
Dietary fish meal level (g kg-1)

Trials Conducted by a Salmon Feed Manufacturer





2. Novel Concepts in Disease Management

Better Nutrition = Better Disease Resistance?

Vol. 21: 163–170, 1995 | DISEASES OF AQUATIC ORGANISMS
Dis. aquat. Org. | Published March 30

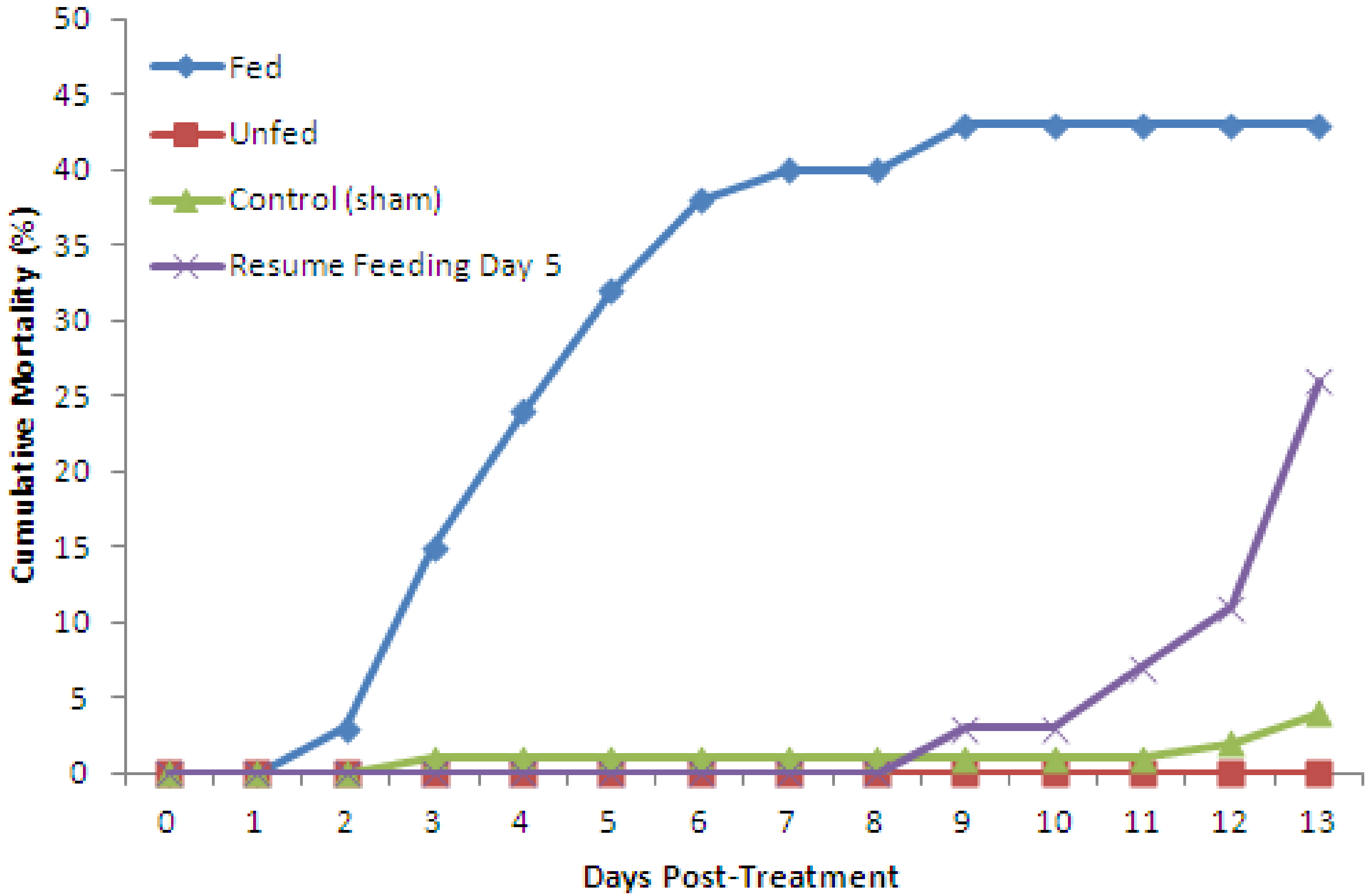
Influence of feeding on the development of bacterial gill disease in rainbow trout *Oncorhynchus mykiss*

D. D. MacPhee, V. E. Ostland, J. S. Lumsden, J. Derksen, H. W. Ferguson*

Fish Pathology Laboratory, Department of Pathology, Ontario Veterinary College, University of Guelph, Guelph, Ontario, Canada N1G 2W1

Magic "nutritional" bullet against bacterial gill disease!

Cumulative mortality of rainbow trout challenged with *Flavobacterium branchiophilum* and subjected to different feeding regimes



Effect of exposure to a mycotoxin (deoxynivalenol) on resistance of rainbow trout to coldwater disease

Ian Ryerse

MSc. Candidate

Supervisors: Dr. John Lumsden, Dr. Dominique Bureau and Dr. Tony Hayes

Ontario Veterinary College

Experimental diets

Daily Feed Intake:

Control:

4 ppm DON:

6 ppm DON:

Pair-fed:

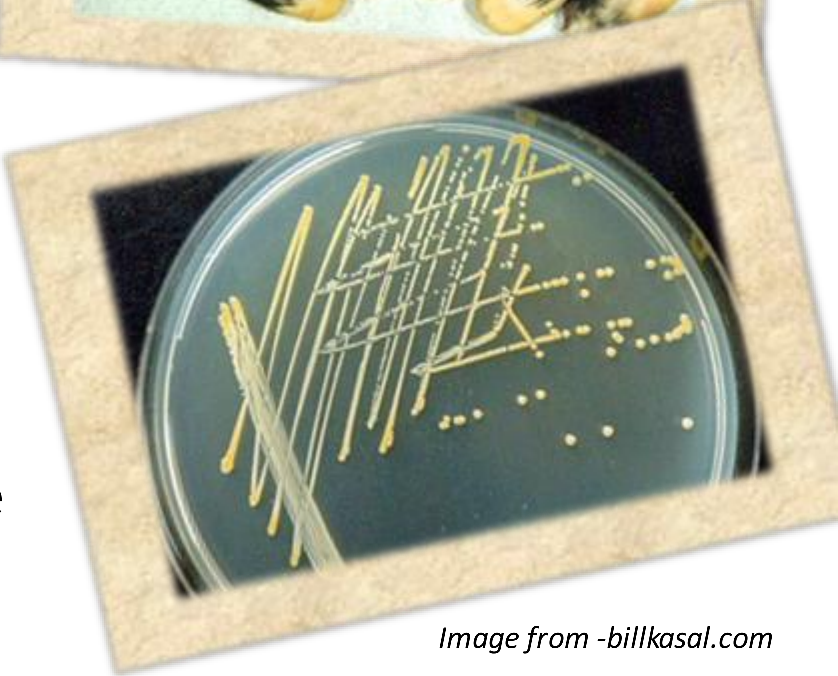
Reduced feed intake

4 - Treatment Groups

1. **Control <0.5 ppm**
2. **4 ppm**
3. **6 ppm**
4. **Pair-fed control <0.5 ppm**

Trial # 1

- 4 treatments
- 40 fish/ tank (7.5 g/fish)
- triplicates
- fed to apprent satiety
- water temperature 11 C
  - ideal for *F. psychrophilum*

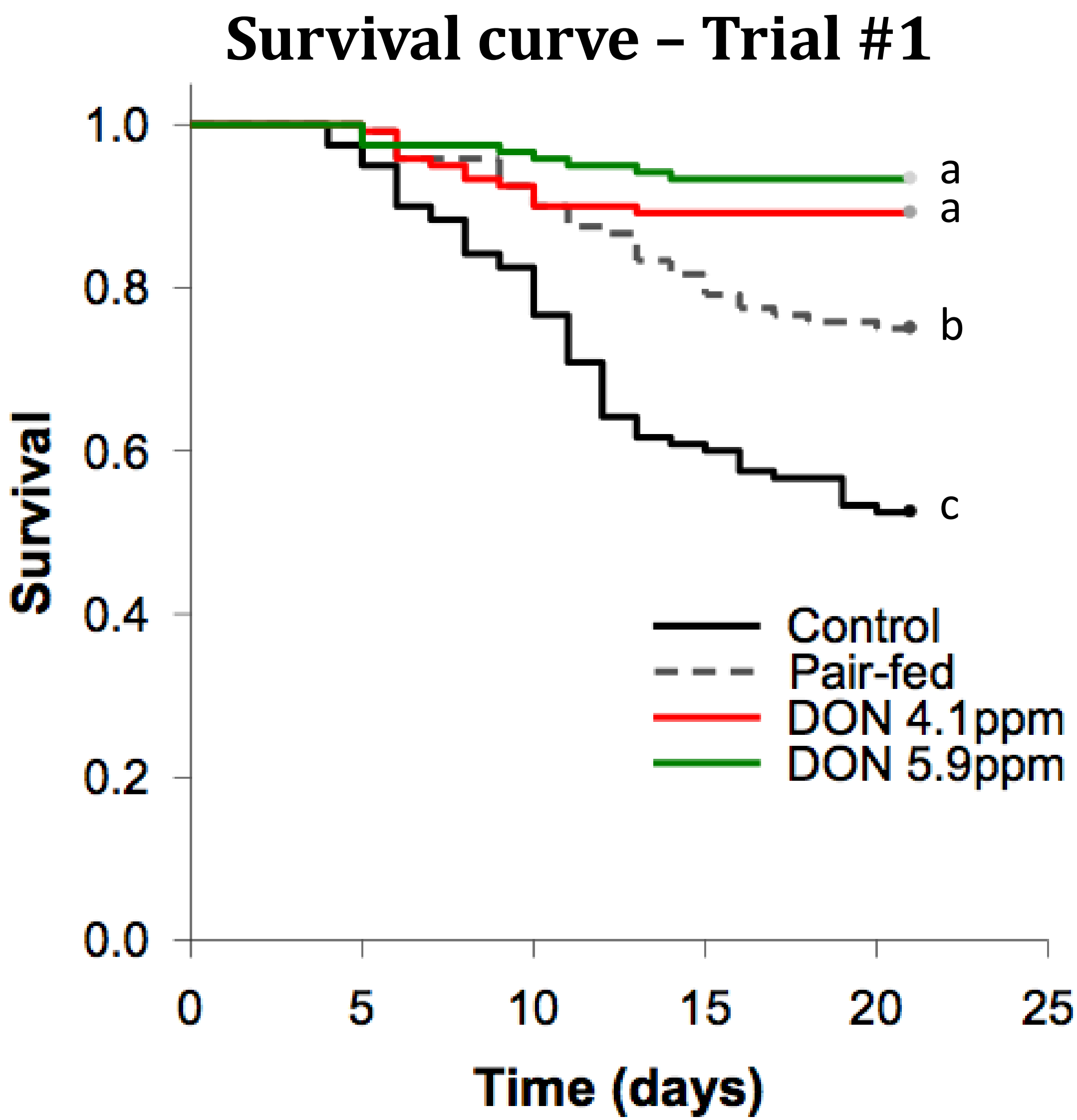


Experimental Infection (i.p.)

- $5x10^6$ CFU/mL *F. psychrophilum* (100uL)
- controls – sham infected – sterile broth

Image from -billkasal.com

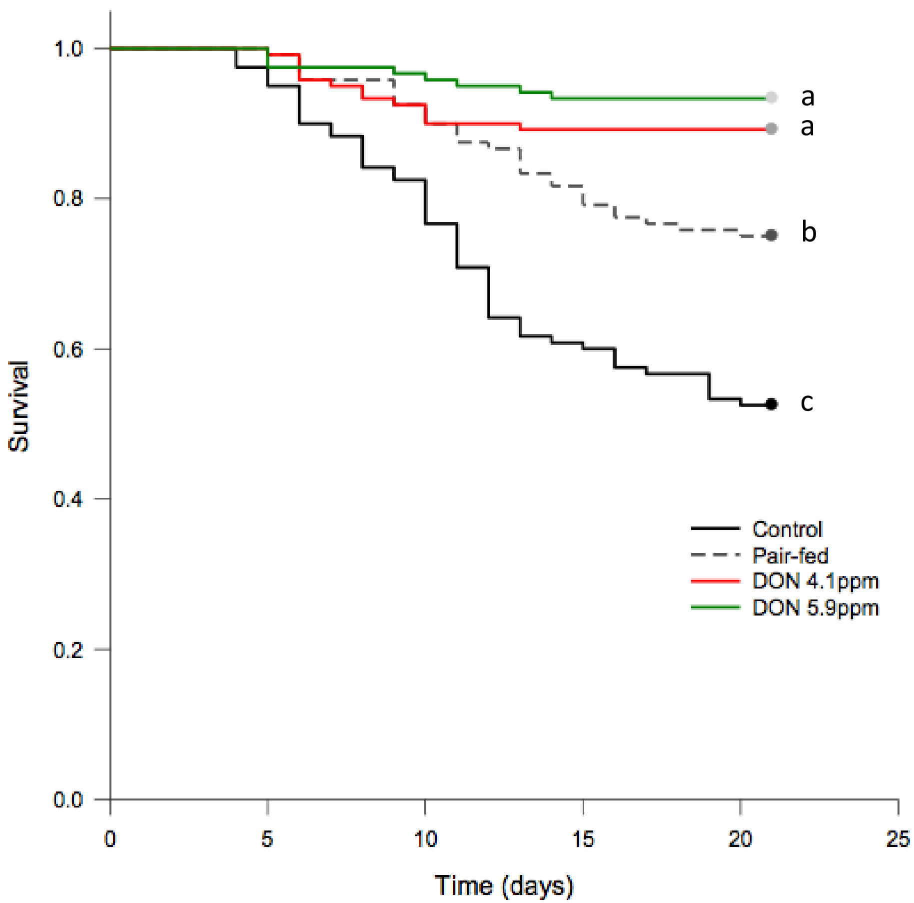
Results: Survival Curve



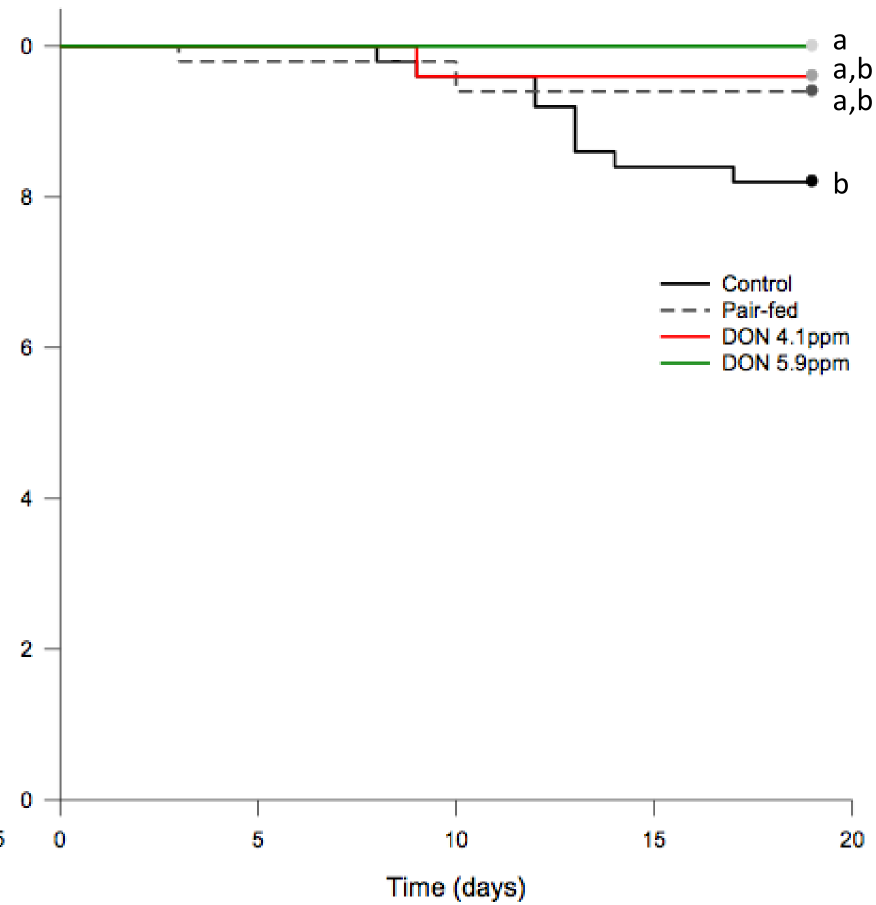
*All curves significantly differed in comparison to control and pair-fed groups (Holm-Sidak, $p<0.05$)

Results: Survival Analysis

Trial # 1

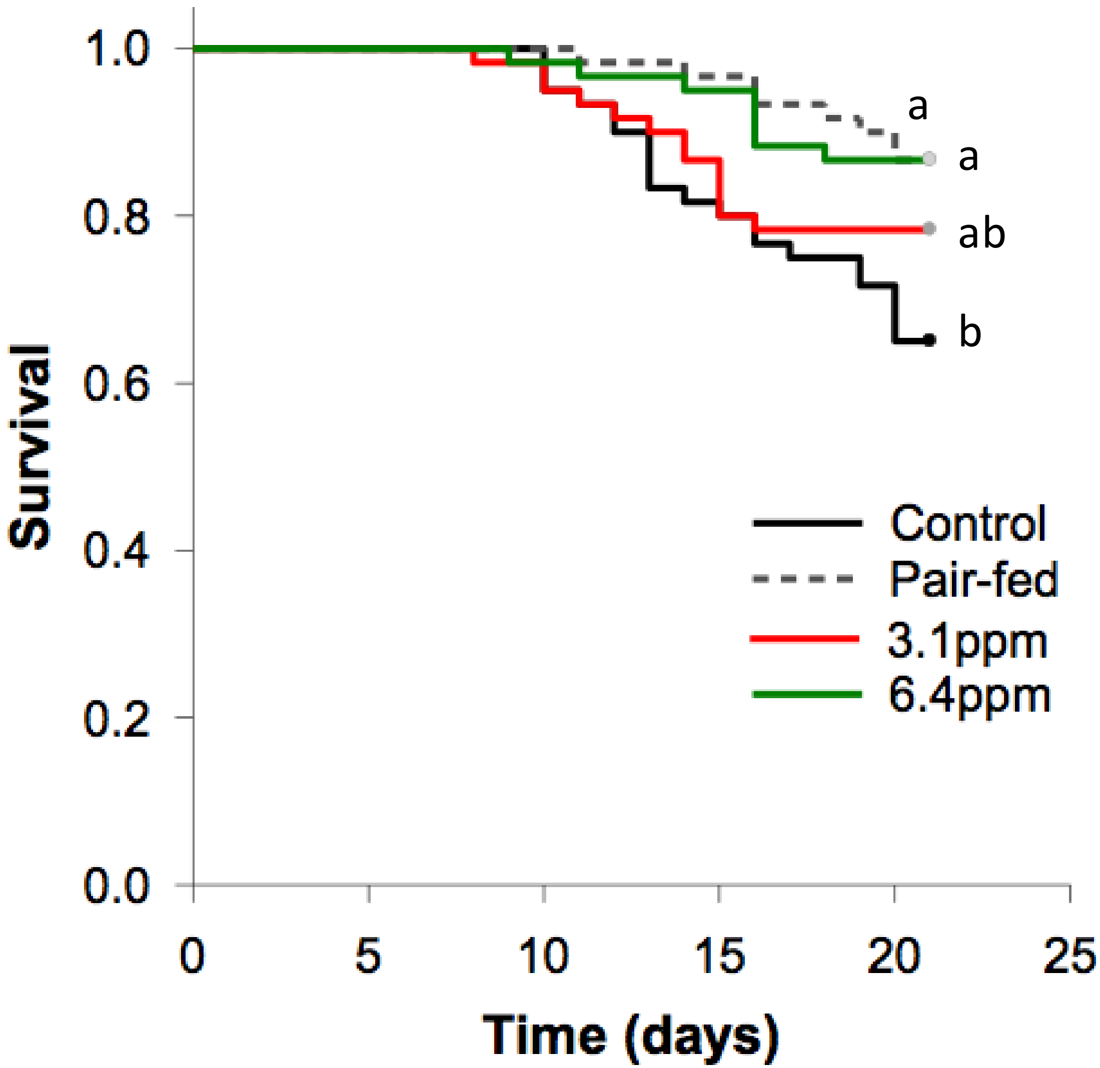


Replicate trial



Results

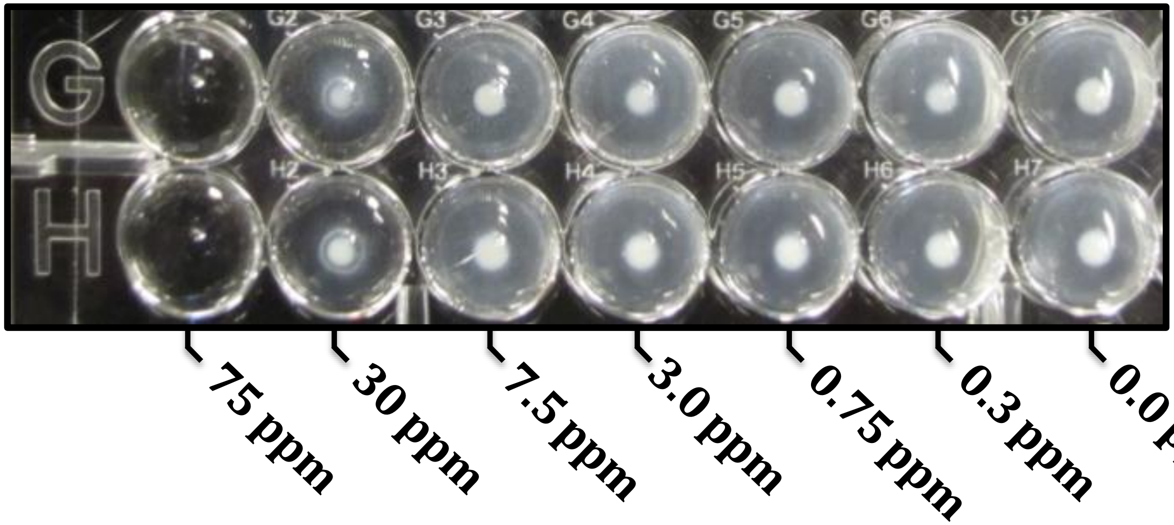
Survival curve – Trial #2



*Pair-fed and 6 ppm group significantly differed in comparison to the control fed group (Holm-Sidak, $p<0.05$)

Results

Inhibitory action of DON on the growth of *F. psychrophilum*



"DON residues **do not** appear to accumulate in tissues to any appreciable extent"

- Prelusky and Trenholm, 1992

- No significant findings from blood work

Better Nutrition = Better Disease Resistance?
No, not necessarily!

The paradigm “Better nutrition equals better disease resistance” is not always true.

In some cases, nutrient supply can have a negative effect on the ability of the animal to cope with pathogens and stress (at least for Flavobacterium spp. Infections)

Relative to feeding or supply of specific nutrients (needed by pathogens?)

Most effective strategy? STOP FEEDING! (for several days)

Potential implications:

Potential for developing feeding strategies and diets for disease states?

Cataract : Causes and Management

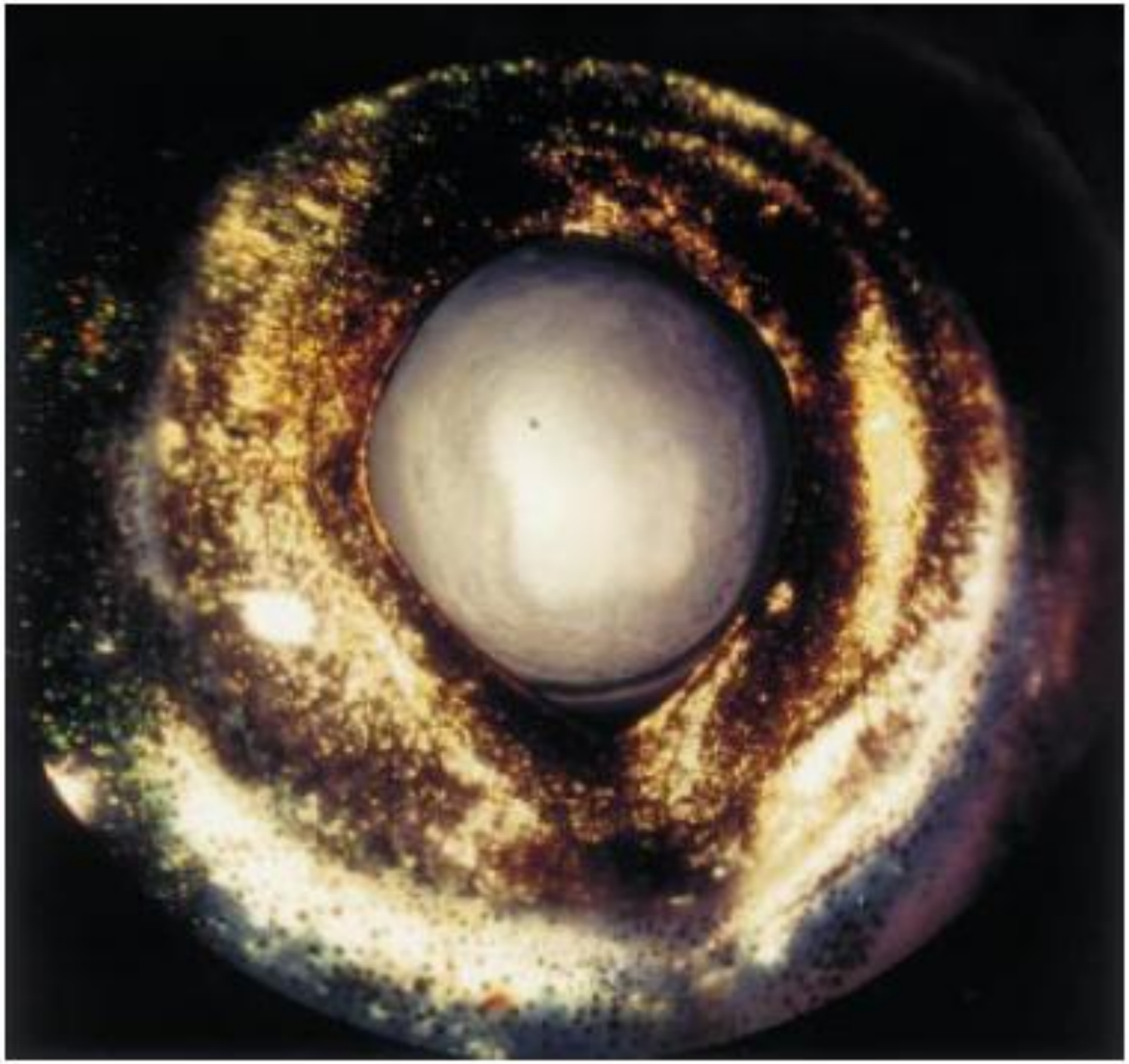


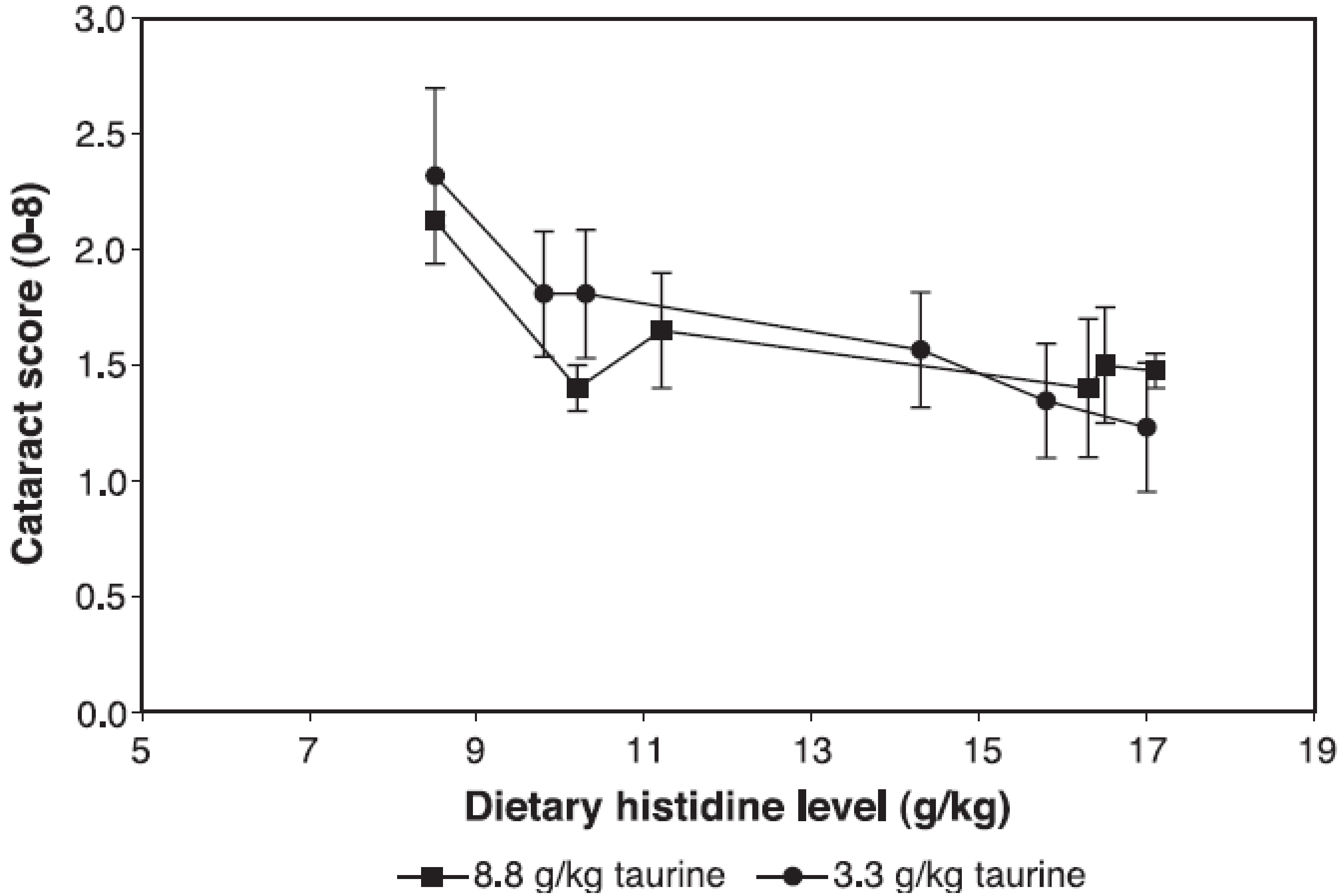
Figure 3 Complete cataract. The white and opaque lens can be seen through the pupillary opening.

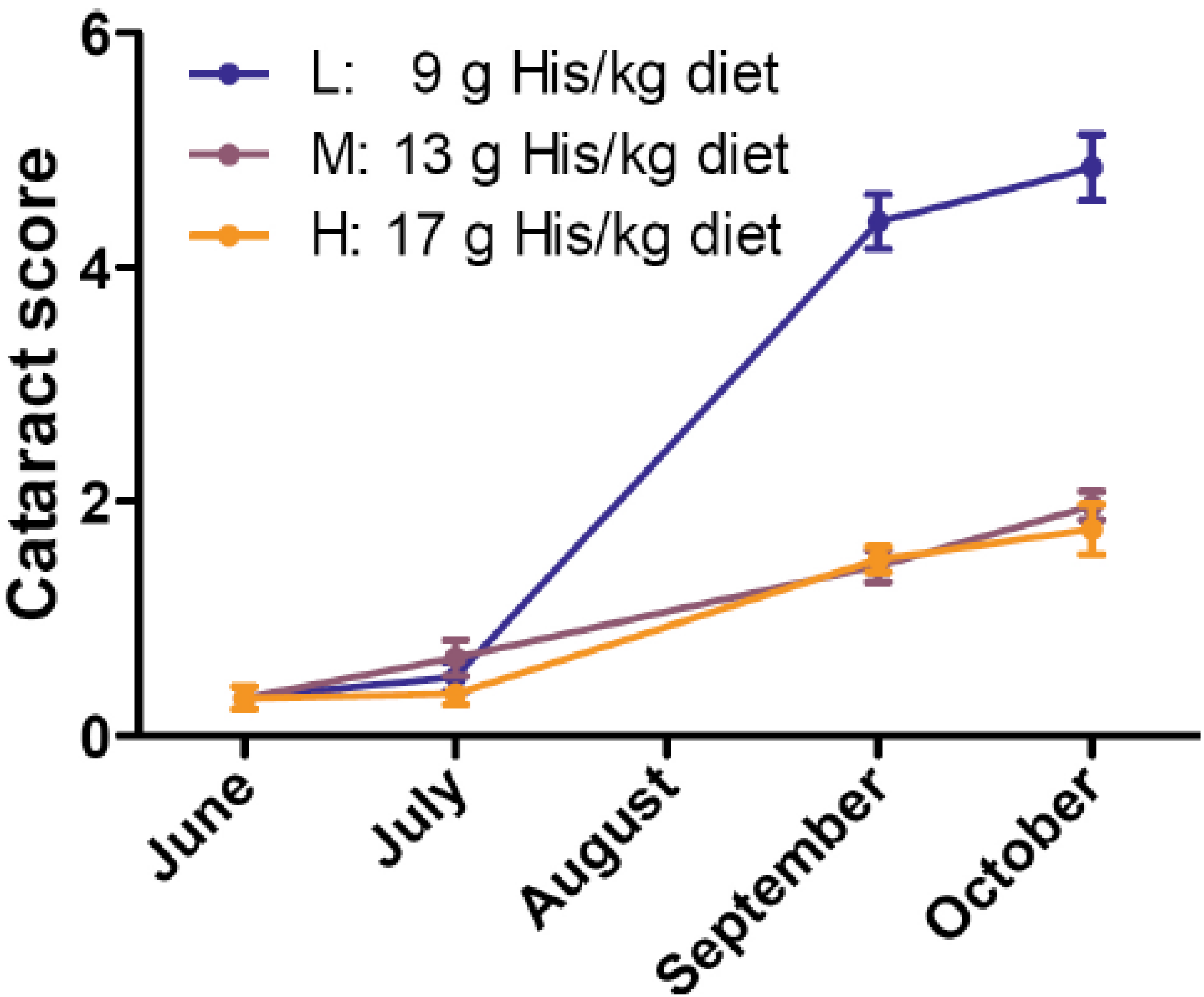
Possible Causes of Cataracts in Salmonids

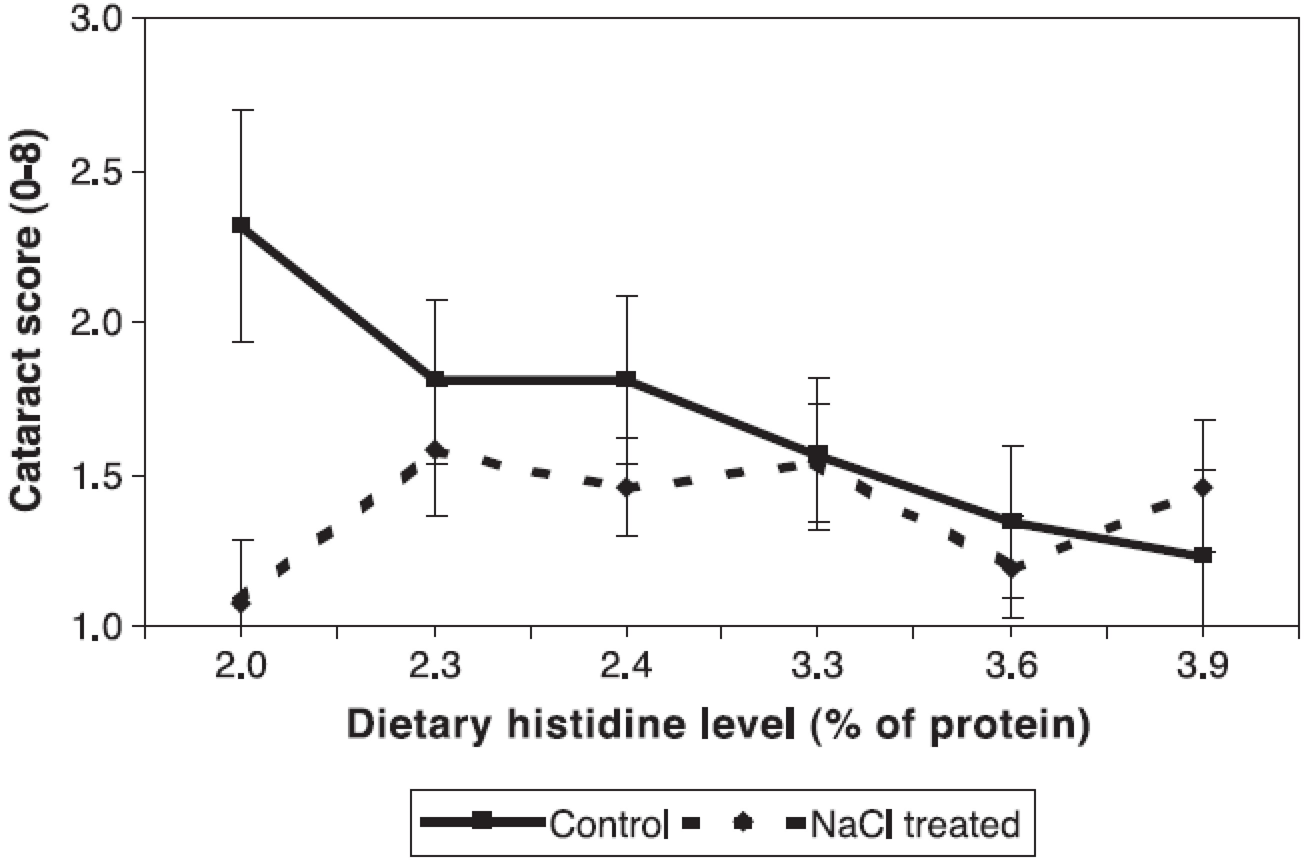
1. Rapid changes in water temperature (Bruno DW & Raynard RS 1994. Bull. EAFP 14: 86-88)
2. Rapid changes in water salinity (Iwata M et al. 1987. Aquaculture 66; 315-327)
3. UV irradiation (Doughty MJ et al. 1997. J. Photochem. Photobiol. 41:165-172)
4. Gas supersaturation (Krise WF & Smith RA 1993. Prog. Fish Cult. 55: 177-179)
5. Organophosphate treatment (Fraser PJ et al. 1990. Exp. Eye Res. 50:443-447)
6. Corneal damage, especially in marine species (Doughty MJ et al. 1997. J. Photochem. Photobiol. 41:165-172)
7. Eye flukes (Ashton et al. 1969. J. Small Anim. Pract. 10: 471-478)
8. Genetic predisposition (Kincaid HL, 1989)
9. Triploidy (Wall AE & Richards RH 1992. Veterinary Record 131: 553-557)
10. Rapid growth rate (Bjerkaas E et al. 1996. Acta vet. Scand 37: 351-360)
11. High summer/early autumn season (Wall AE 1998. Veterinary Record 142, 626-631; Crockford et al. 1990)
12. High seawater temperatures (Crockford et al. 1998)
13. Dietary zinc deficiency (Ketola HG 1979, J. nutr. 109: 965-969)
14. Tryptohan deficiency (Poston HA & Rumsey GL 1983. J. nutr. 113: 2568-2577)
15. Methionin deficiency (Cowey et al. 1992. J. nutr 122: 1154-1163)
16. High-energy diets (Waagbo et al. 1998. Bull. EAFP 18: 201-205)
17. Histidine deficiency
18. Folate / Vit B12 deficiency

The influence of nutritional and environmental factors on osmoregulation and cataracts in Atlantic salmon (*Salmo salar* L)

Ellen Bjerkås[a,*], Harald Sveier[b]




Cataract score
6
4
2
0
L: 9 g His/kg diet
M: 13 g His/kg diet
H: 17 g His/kg diet
June
July
August
September
October


3.0
2.5
2.0
1.5
1.0
Cataract score (0-8)
2.0
2.3
2.4
3.3
3.6
3.9
Dietary histidine level (% of protein)
Control
NaCl treated

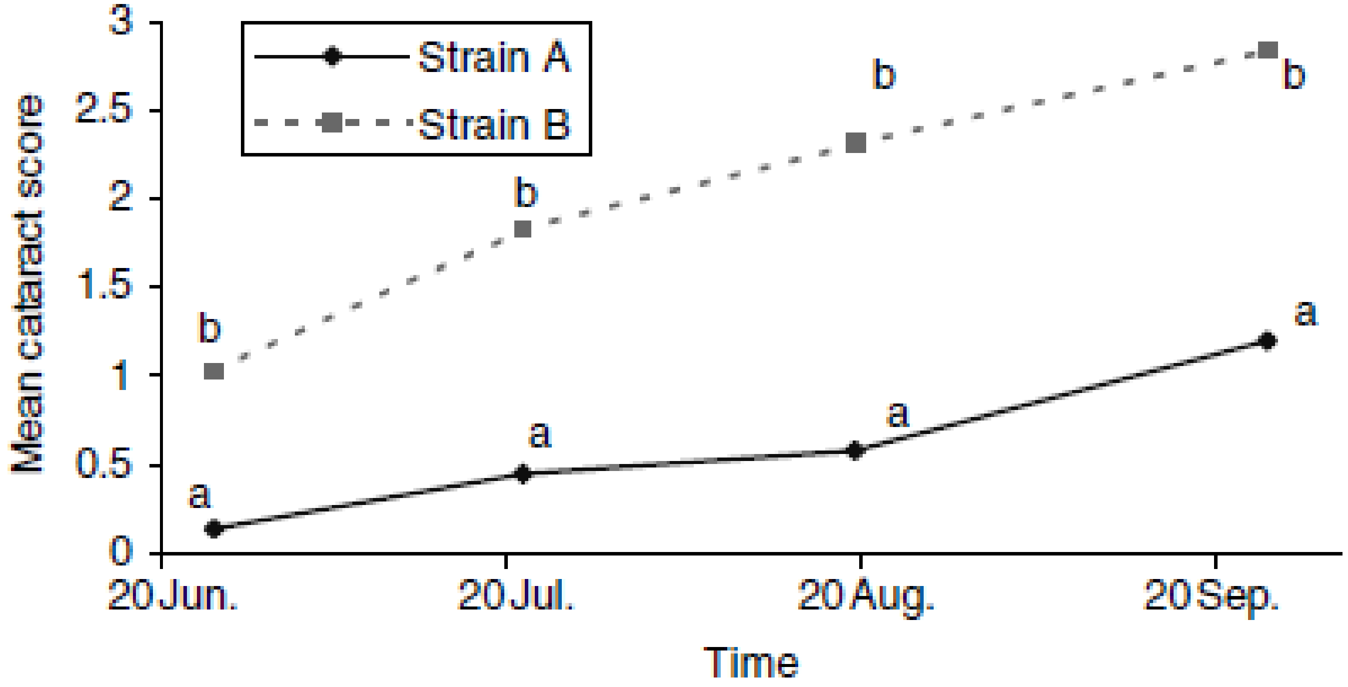


Figure 2 Development of cataracts in Strains A and B in Trial 2. The values represent mean scores of pooled individual data from all dietary groups within each strain. Different letters denotes significant differences between the two strains at each sampling point ($P < 0.05$).

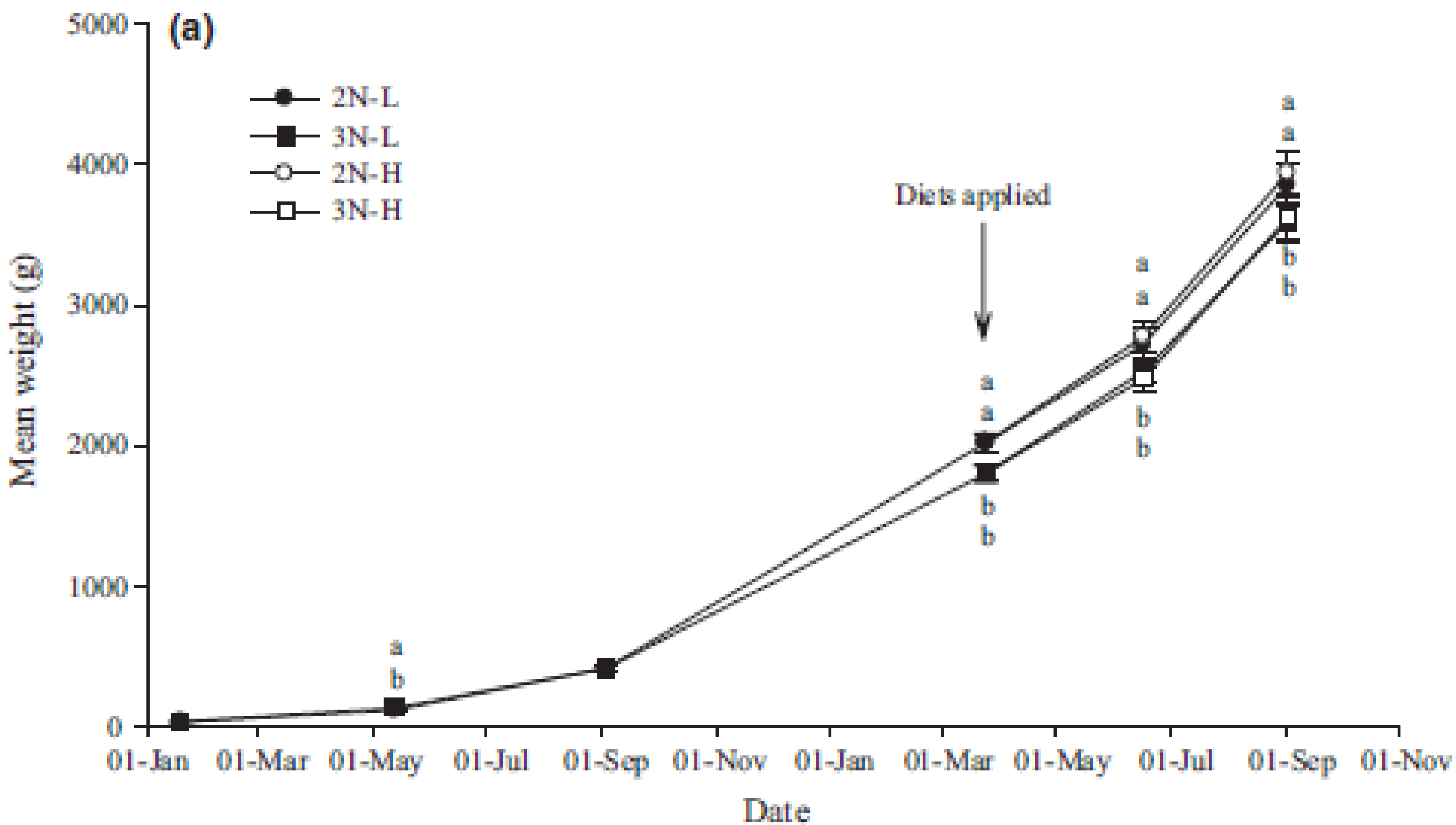
Aquaculture Nutrition

Aquaculture Nutrition 2014 doi: 10.1111/anu.12130

Adult triploid Atlantic salmon (*Salmo salar*) have higher dietary histidine requirements to prevent cataract development in seawater

J.F. TAYLOR[1], R. WAAGBØ[2], M. DIEZ-PADRISA[3], P. CAMPBELL[4], J. WALTON[4], D. HUNTER[3], C. MATTHEW[1] & H. MIGAUD[1]

[1] *Institute of Aquaculture, University of Stirling, Stirling, UK;* [2] *National Institute of Nutrition and Seafood Research (NIFES), Bergen, Norway;* [3] *Marine Harvest Scotland, Fort William, UK;* [4] *Biomar UK Ltd., Grangemouth, UK*



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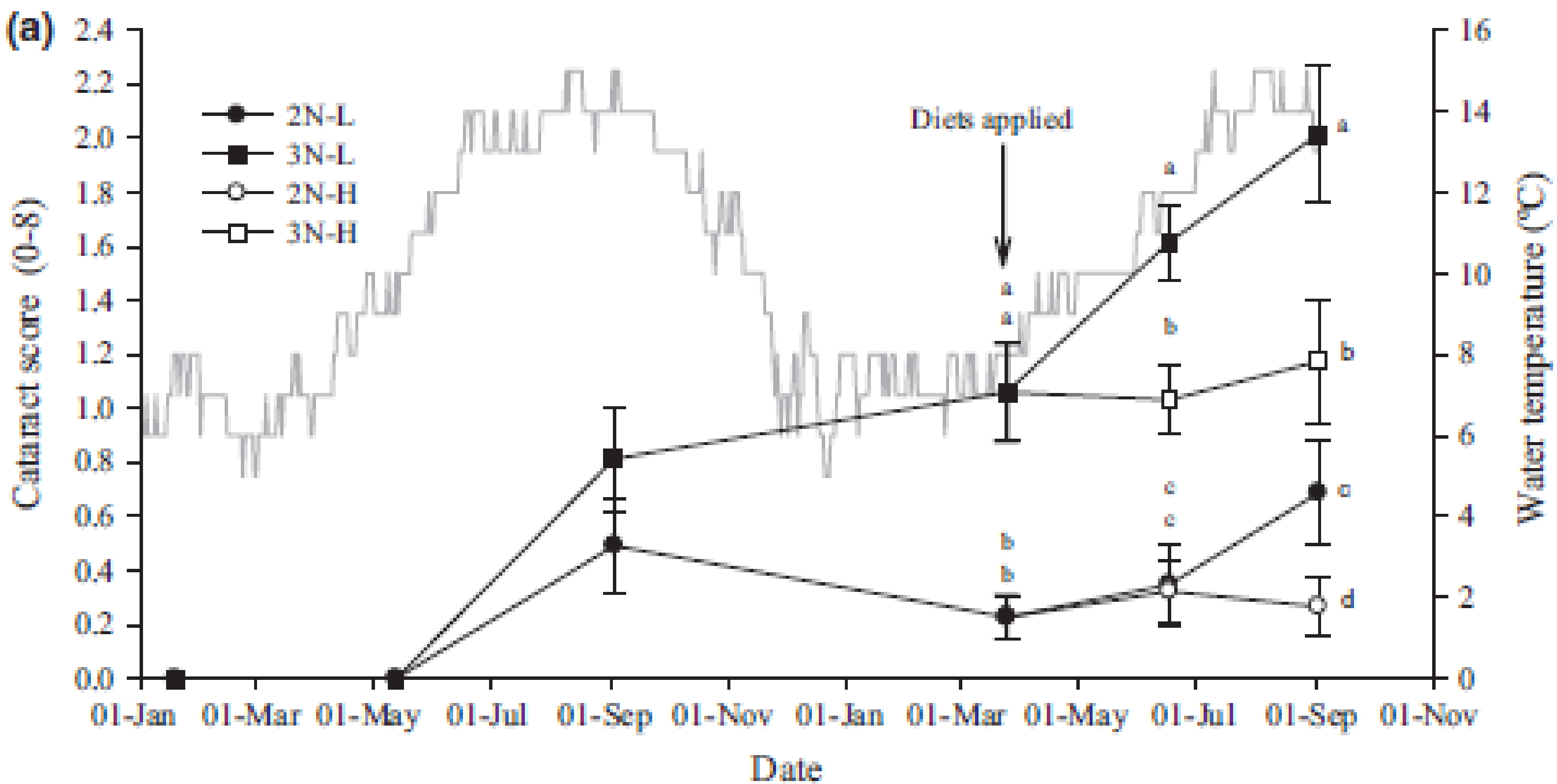


The influence of nutritional and environmental factors on osmoregulation and cataracts in Atlantic salmon (*Salmo salar* L)

Ellen Bjerkås[a,*], Harald Sveier[b]

Dietary histidine level	Salinity	Water temperature
Normal Tank 1,4,5,8,9,12,14,16,17,19,20,23	**Normal** Tank 1,4,8,12,14,20	**Normal** Tank 1,4,20
		High Tank 8,12, 14
	Fluctuating Tank 5,9,16,17,19,23	**Normal** Tank 5,19,23
		High Tank 9,16,17
High Tank 2,3,6,7,10,11,13,15,18,21,22,24	**Normal** Tank 2,6,7,10,15,22	**Normal** Tank 2,6,22
		High Tank 7, 10, 15
	Fluctuating Tank 3,11,13,18,21,24	**Normal** Tank 3, 21, 24
		High Tank 11,13,18

Fig. 1. The different tank conditions in Study 5. The two levels of histidine were 1.8% (normal) and 3.4% (high) of dietary protein. Salinity was stable (30 ppm) or fluctuating between 30 and 15 ppm. Water temperature was either maintained at normal level (8 °C) or raised to 13 °C.

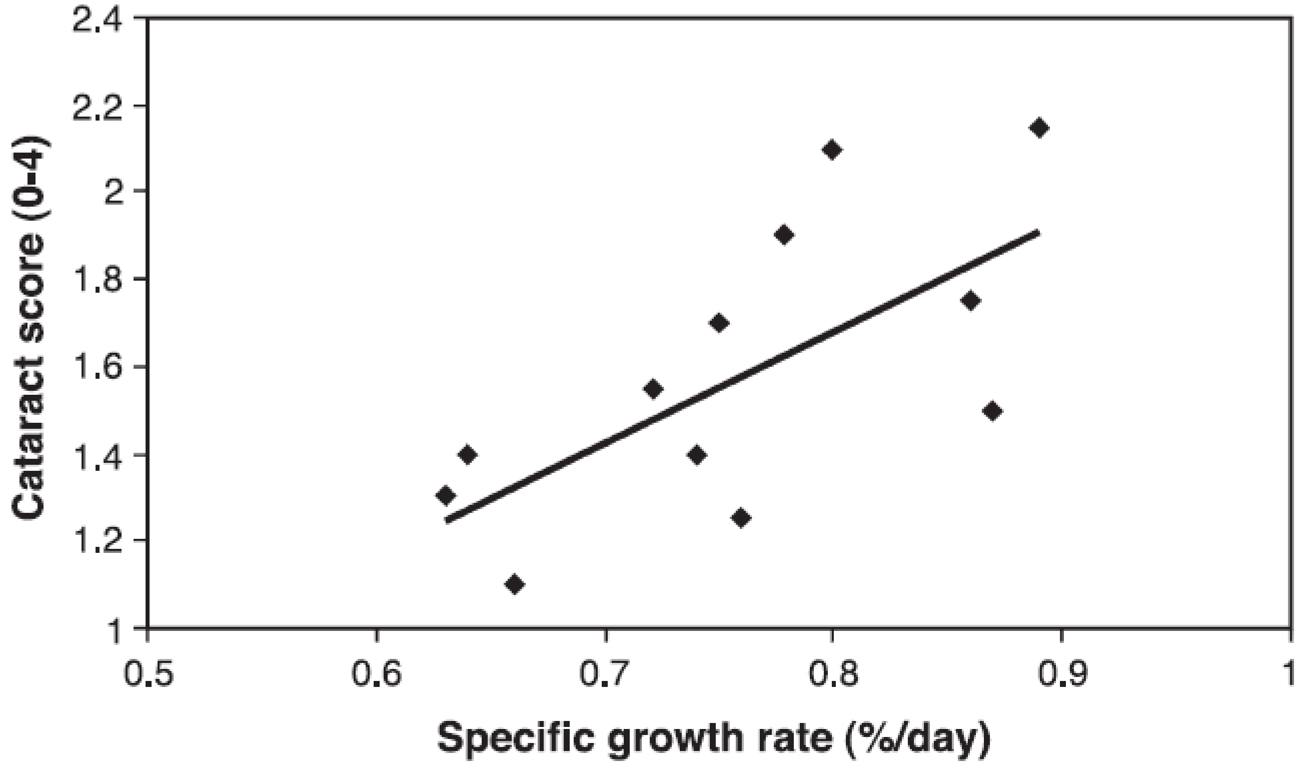
The influence of nutritional and environmental factors on osmoregulation and cataracts in Atlantic salmon (*Salmo salar* L)

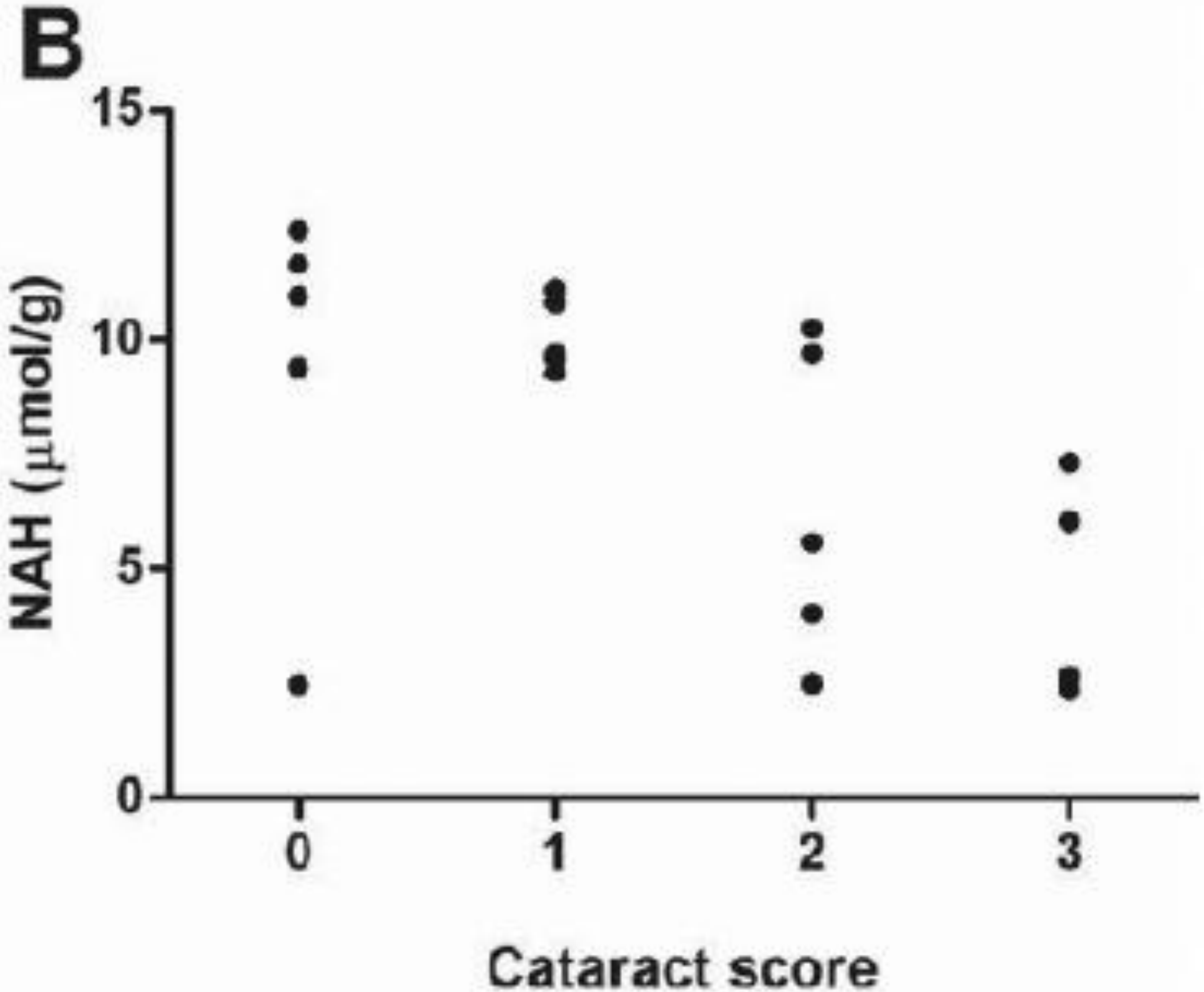
Ellen Bjerkås[a,*], Harald Sveier[b]

Table 4
The effect of dietary histidine level, NaCl feeding and environmental factors on cataract score (± S.D.) at the final sampling in Study 5

	Normal histidine	High histidine	*p*-value	Significance
Without NaCl	1.18 ± 0.14	0.77 ± 0.09	0.02	*
With NaCl	1.18 ± 0.16	0.81 ± 0.11	0.07	Ns
Stable salinity	1.18 ± 0.16	0.84 ± 0.11	0.09	Ns
Fluctuating salinity	1.17 ± 0.14	0.73 ± 0.08	0.02	*
Normal temperature	0.75 ± 0.07	0.78 ± 0.11	0.80	Ns
High temperature	1.60 ± 0.08	0.79 ± 0.09	< 0.001	***

Significant effects are marked with asterisks (*).


2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.5
0.6
0.7
0.8
0.9
1
Cataract score (0-4)
Specific growth rate (%/day)


B
15
10
5
0
NAH (μmol/g)
0
1
2
3
Cataract score

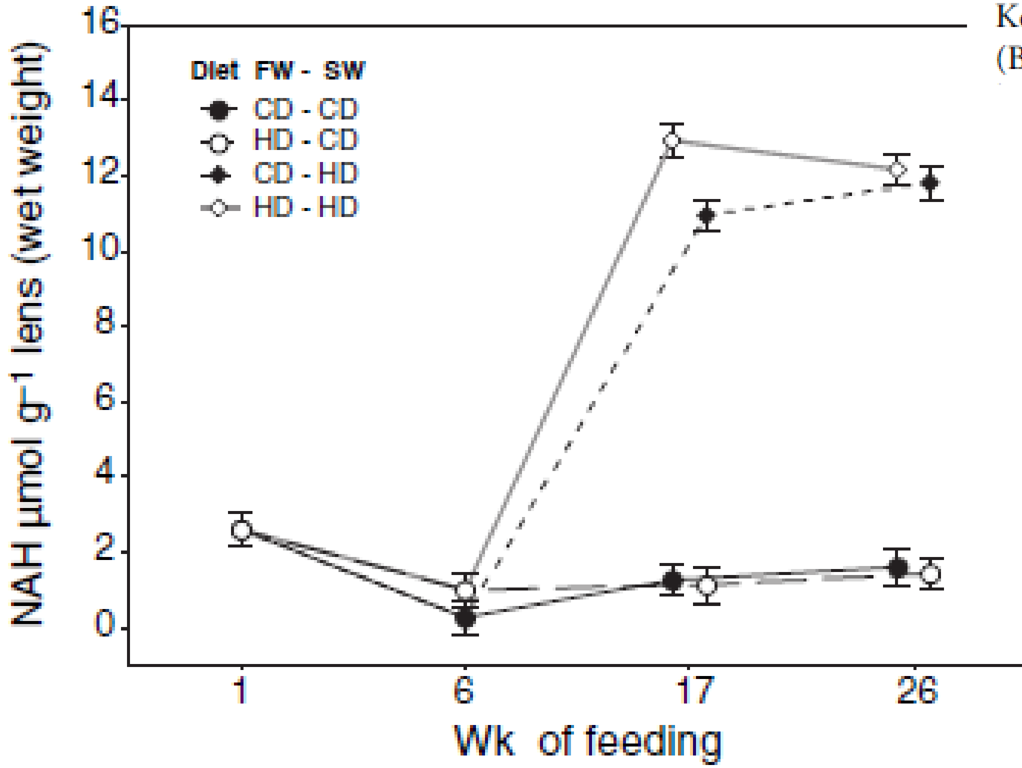
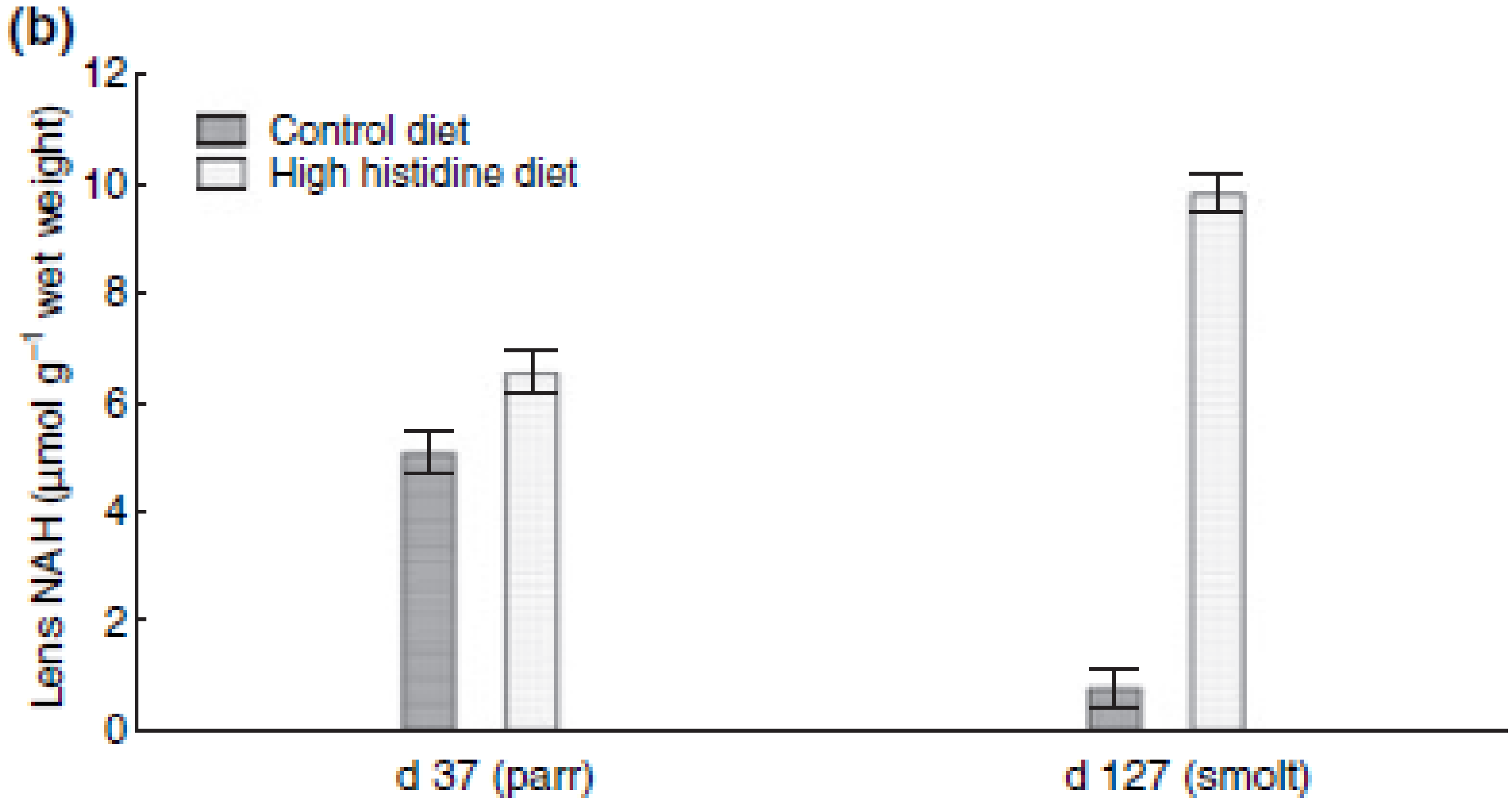


Figure 5 Levels of lens *N*-acetyl histidine (NAH; mean ± SEM; $n = 6$ pooled samples) in Atlantic salmon given four selected feeding regimes throughout the trial, based on pooled strain data (FW, fresh water; SW, sea water; CD, control diet; HD, high histidine diet). Dietary regimes were changed at week 6 and the fish were transferred to SW at week 9.

The role of elevated NAH and His levels in the lens in preventing cataracts could be explained by the general characteristic of imidazol-containing compounds as good tissue buffering agents (Ogata, Konno & Silverstein 1998) and antioxidants (Babizhayev 1989; Wade & Tucker 1998). The

Dietary histidine affects lens protein turnover and synthesis of N-acetylhistidine in Atlantic salmon (*Salmo salar* L.) undergoing parr–smolt transformation

O. BRECK[1,5], E. BJERKÅS[2], J. SANDERSON[3], R. WAAGBØ[1] & P. CAMPBELL[4]
[1] *National Institute of Nutrition and Seafood Research (NIFES), Bergen;* [2] *Norwegian School of Veterinary Science, Oslo, Norway;* [3] *University of East Anglia, Norwich;* [4] *Biomar Ltd., Grangemouth, UK;* [5] *Marine Harvest Norway AS., Bergen, Norway*

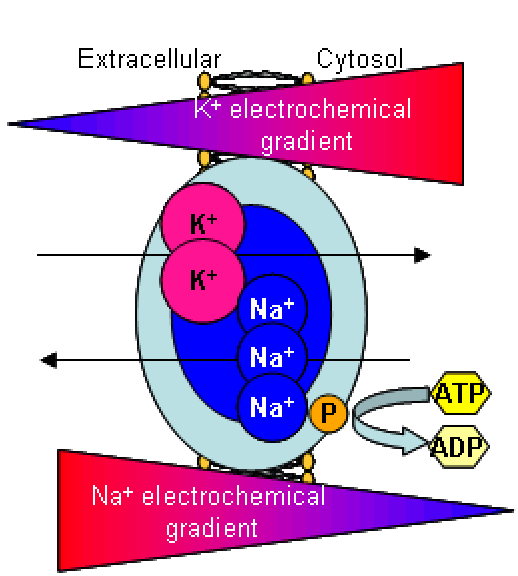


The lens fiber cells are normally held in a relatively dehydrated state by the action of the Na+/K+ pump.

Changes in the Na+, K+ and Cl- permeability of the lens can alter the ability of the lens to control its swelling.

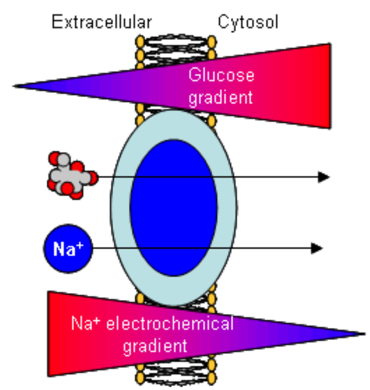
Consequently, any agent, event or factor that increase permeability of the lens membrane can comprise the clarity of the lens

Ion	Blood (mM)	Cell (mM)
K+	5	150
Na^+	145	12
Cl^-	125	4
Ca^{2+}	1.8	0.0002



Maintenance of electrolyte gradients requires energy

Electrolyte excretion:
energy demanding process



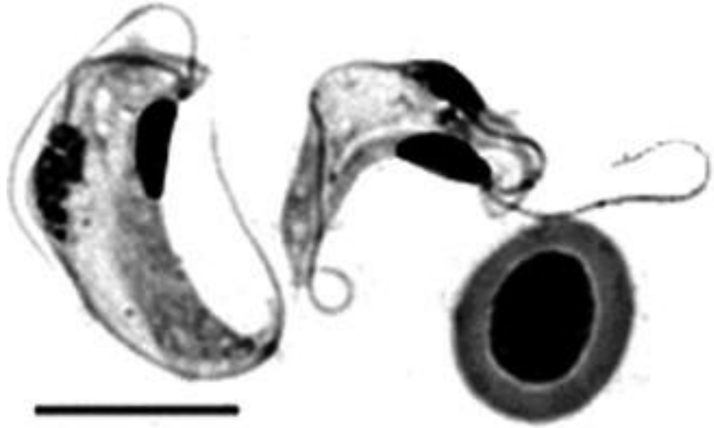
Electrolyte gradients:
required for nutrient transport

Stressors:

- Environmental - temperature, oxygen level, pollutions, predators….
- Physiological - fasting, infections, and reproduction (such as maturation, migration, mating behaviours…) are stressful processes;

Stress results in animal plasma cortisol level increase to combat the unsuitable environment

Cryptobia salmositica



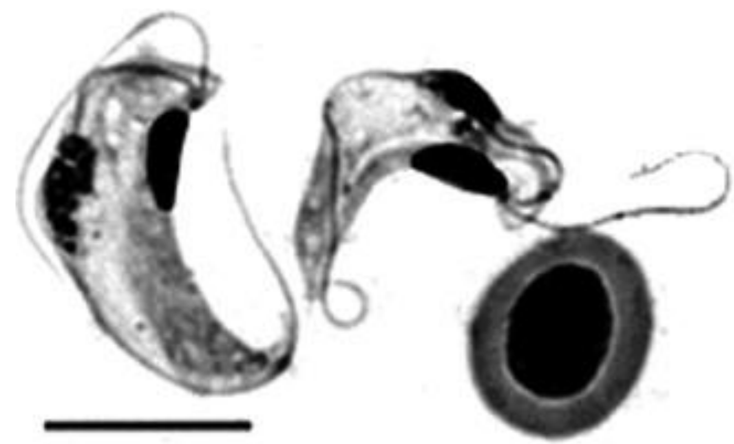
Pathogenic haemoflagellate parasite found in salmonids on west coast of North America.

About the size of red blood cell

Stress vs. Susceptibility to Parasites (Cryptobiosis)

↑ Stress, ↑ Cortisol

↓Immune Response



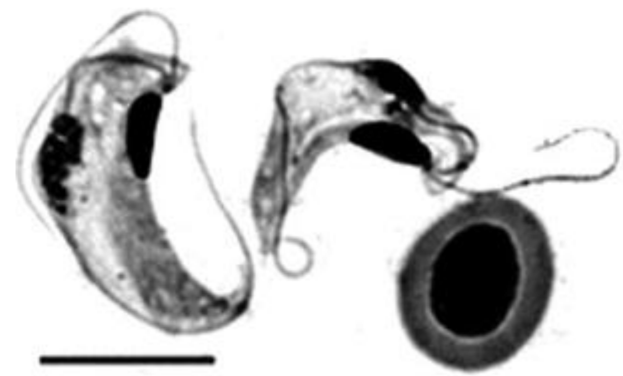
↑Susceptibility to infection
↑Multiplication of parasites

1. Elevated cortisol level (implant) suppressed immunocapacity and increased parasitaemia in rainbow trout (***Woo et al., J. Fish Biol, 1987***);

Stress vs. Susceptibility to Parasites

↑ Stress, ↑ Cortisol

?



↑Multiplication of parasites

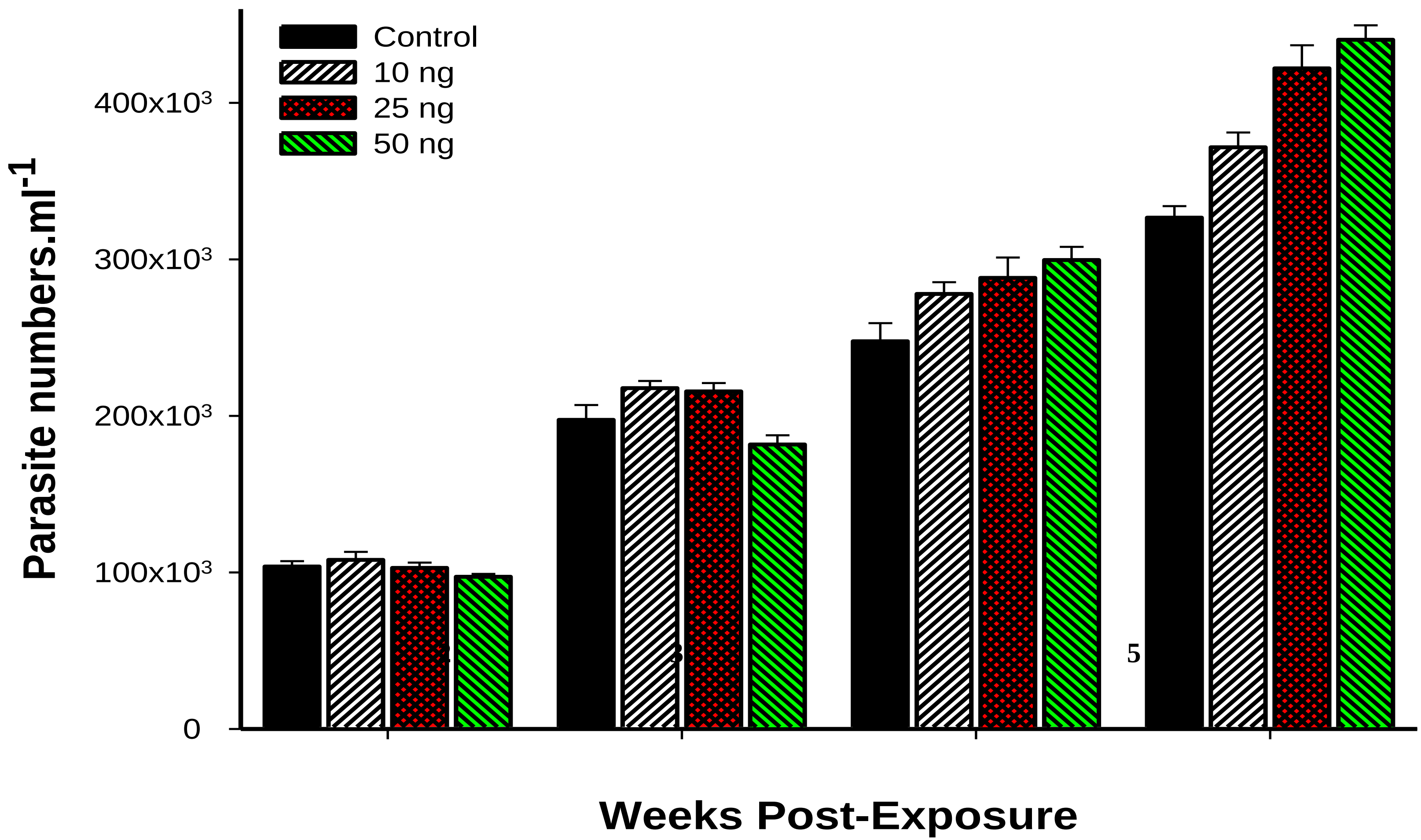
2. Addition of cortisol to cultures (10ng/ml) increased parasite multiplication (*Woo, 2008 unpld*)

The stress hormone, Cortisol, promotes parasite (*Cryptobia salmositica*) multiplication under *in vitro* conditions: Possible applications to aquaculture practices

Mao Li

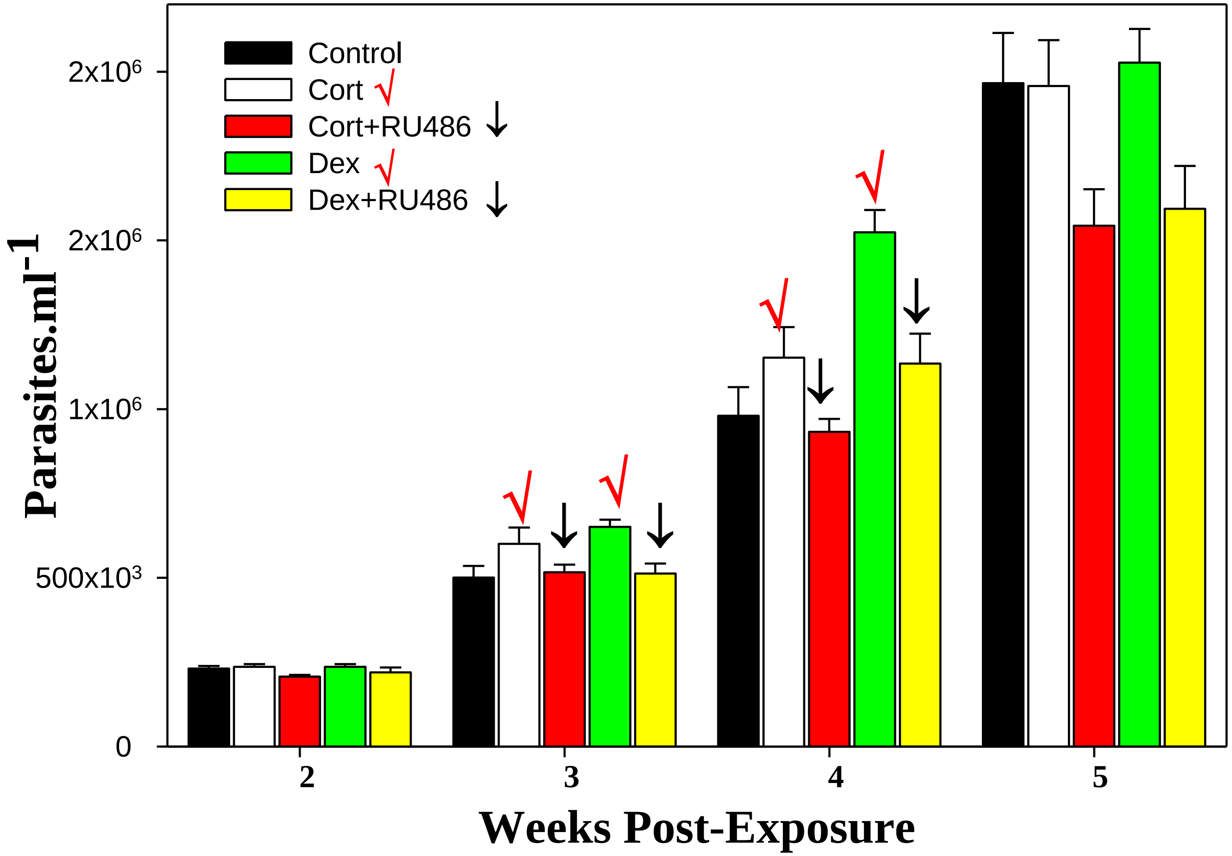
Department of Integrative Biology,
University of Guelph

Results : Cortisol at physiological levels enhance parasite replication



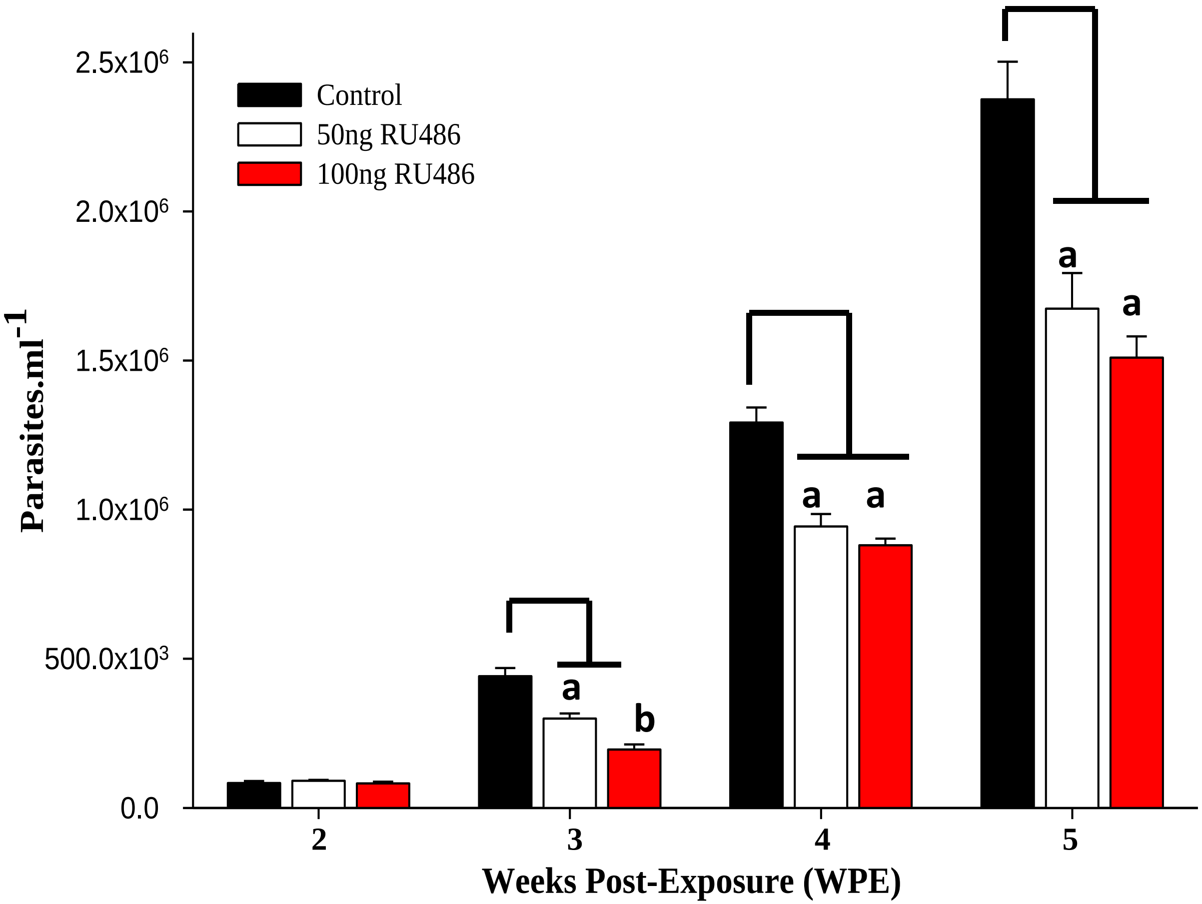
Li et al., IJP (2013)

Result 2: The type of response of parasite to cortisol is similar to that observed in vertebrate cells



-- GR-like protein exists in the parasite!

Result 3: RU486 suppresses parasite multiplication



Li and Woo, IJP (2014)

Implications:

1. RU486 and other inhibitor of corticosteroid hormone synthesis may be used as antagonist to reduce cortisol action in fish culture practice;

2. RU486 and other corticosteroid hormone inhibitors may be used as reagent to combat parasite infection in salmon species;

3. In aquaculture, management of stress should consider in both the host and parasite.

3. Production and Feeding Management

Modeling Growth and Feed Requirements of Fish under Commercial Conditions:

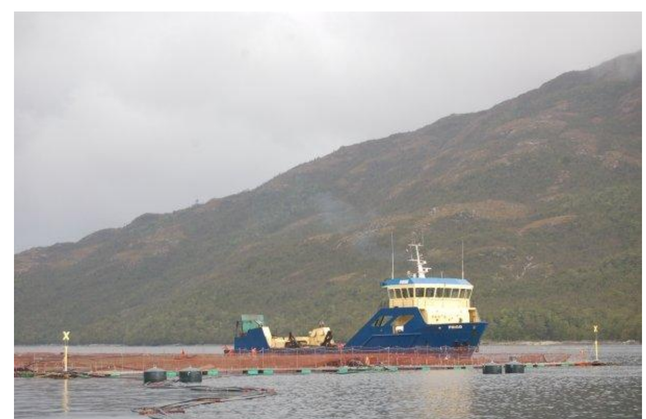
Matching Science and Practice to Improve Efficiency and Sustainability

Fish Nutrition Research Lab
Dept. Animal and Poultry Science | Ontario Ministry of
University of Guelph | Natural Resources

Wanted: Effective Production Management Tools

Aquaculture producers require tools to:

- Manage and/or forecast production
- Estimate feed requirements
- Audit feed conversion ratio (feed:gain) achieved
- Estimate the amount of waste outputs from their facilities



Making Better Use of Information

A lot of information is collected every day/week/month by aquaculture operations.

Much of the information is collected and analyzed in a "piece-meal" fashion (i.e. not very systematically or meaningfully)

How can we make best use of this information?

Example: I may have a lot of information but …

How can I meaningfully compare the growth rate or FCR of groups of fish (or shrimp) reared at two different production sites with different temperature profiles, over a different time periods or live weight intervals and fed different diets?

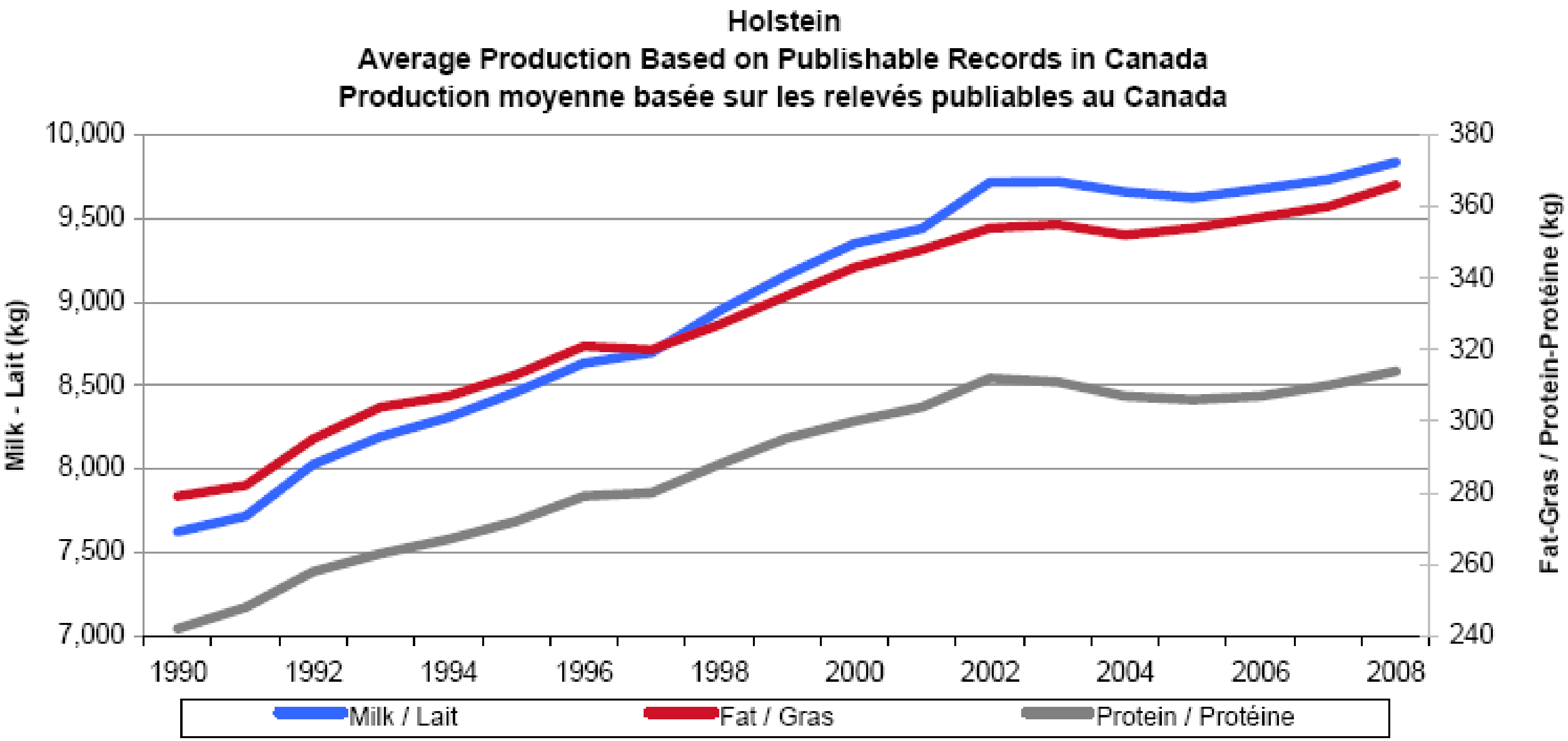
Approaches for Dealing with Current Challenges?

Mathematical models have proven to be very valuable for other animal industries and stand as prominent tools to meet current challenges in aquaculture

Mathematical modeling has been shown to be an effective way of compiling, integrating, and interpreting production information and enabling the development of practical and reliable tools for feed formulation and production, feeding, and waste outputs management.

Dairy producers have been using mathematical models to manage production, breeding and feeding of dairy cows for decades

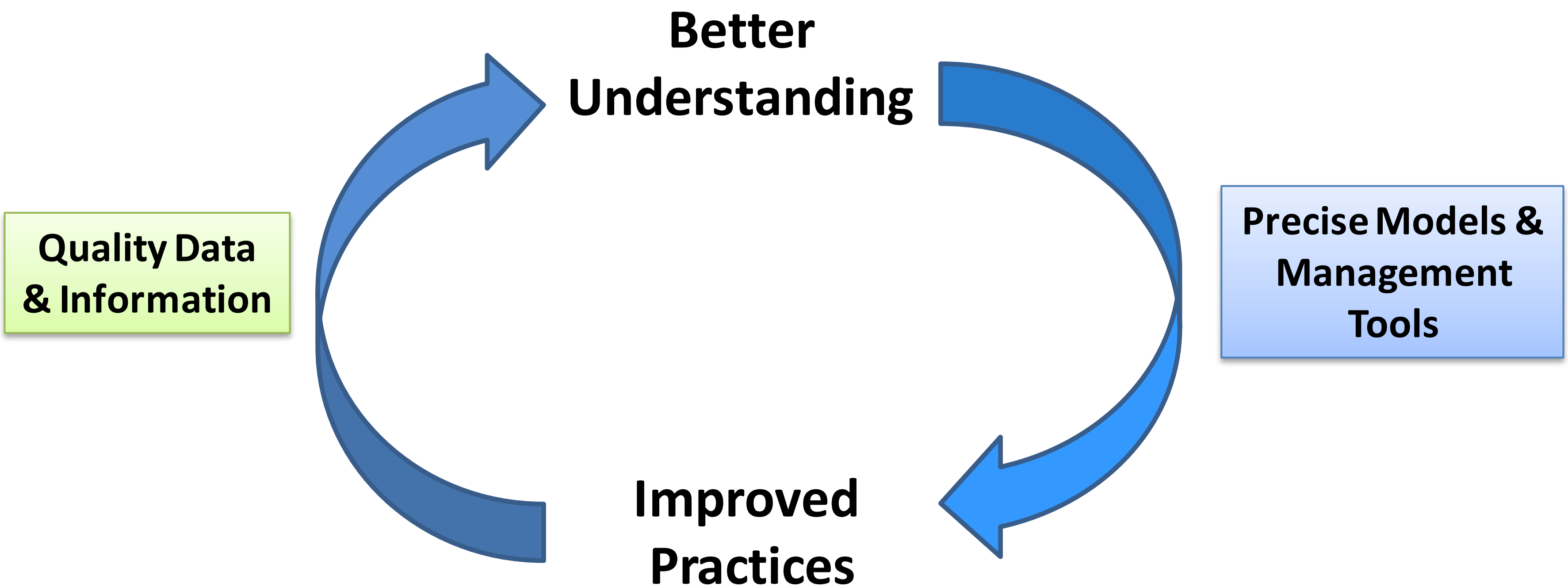
Evolution of Average Production of Holstein Cows in Canada



Attributable to Genetic Gain, Better Feeding and Better Management

Enabled by:
1) systematic recording of performances, 2) sharing of data , 3) very advanced mathematical models and 4) practical tools (genetic selection index, feeding management software, etc.)

Continuous Improvement Framework
(virtuous cycle)

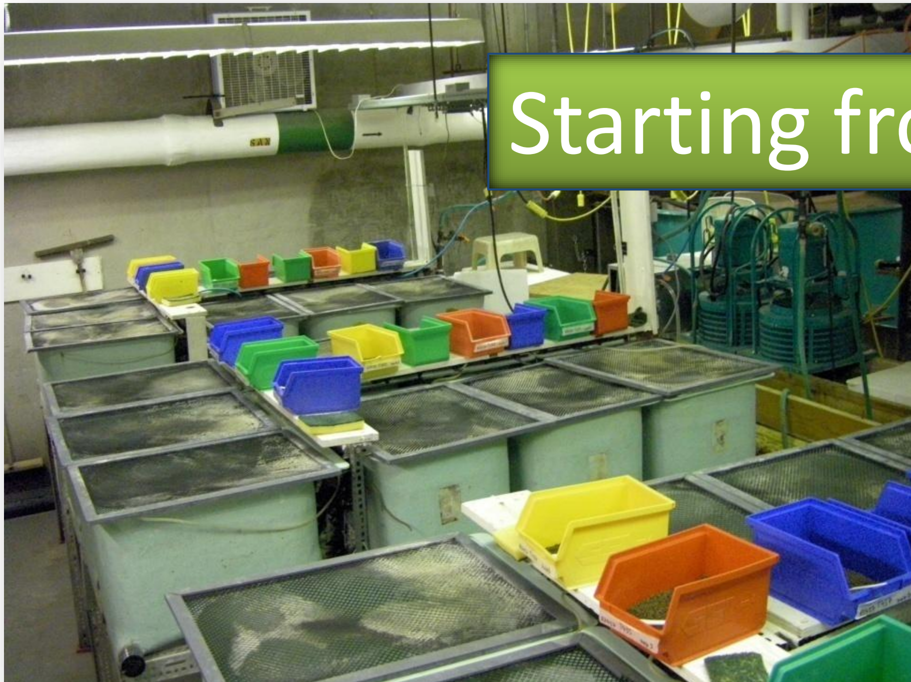


Combining information and models to improve efficiency of production

Mathematical Models as Tools for Dealing with Production Challenges on Fish Culture Operations

From the laboratory to the field…

Starting from the lab….



Simple Growth Model - Only Middle School Maths Required

Thermal-Unit Growth Coefficient (TGC) =

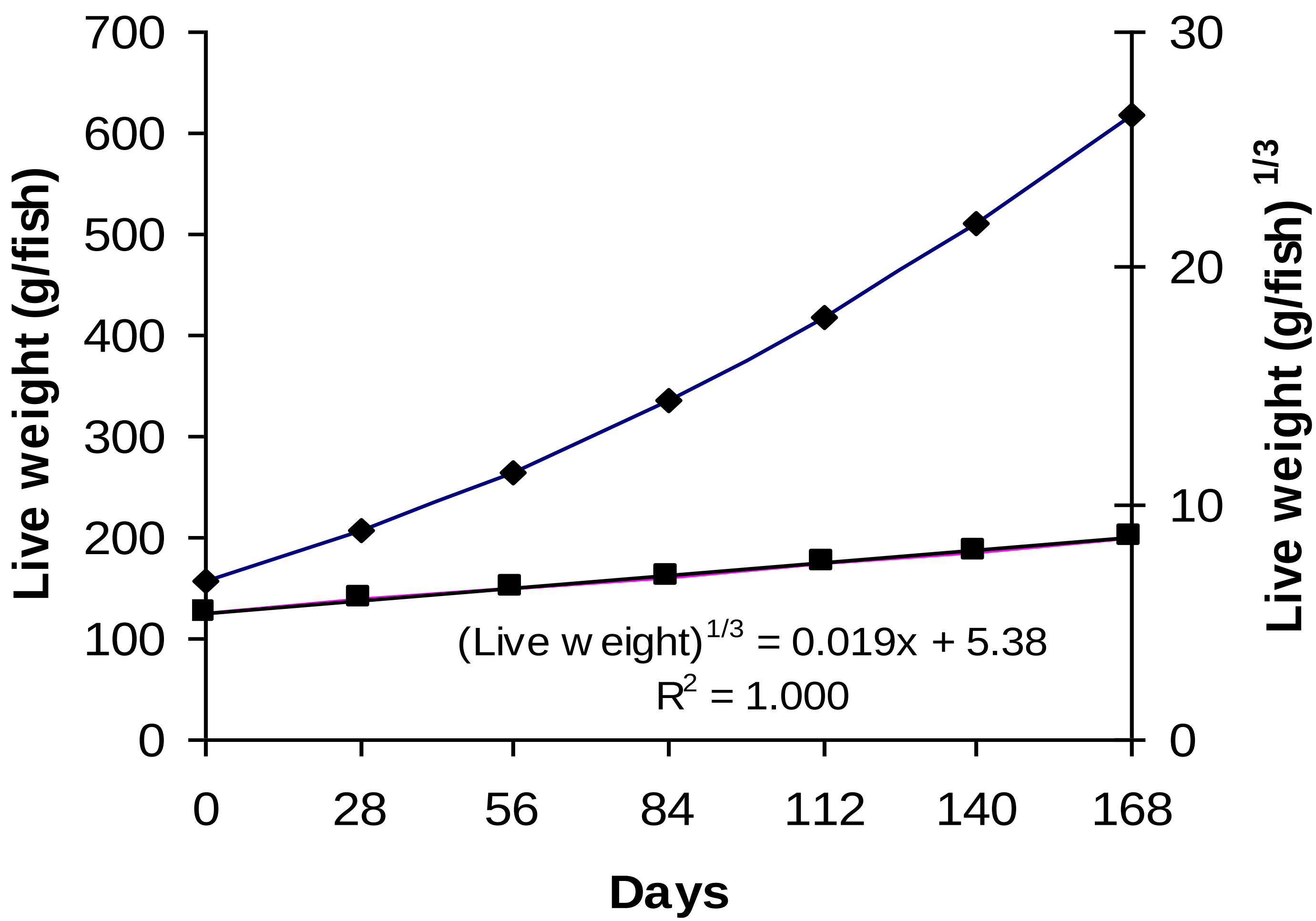
$$\frac{\text{Final Body Weight}^{1/3} - \text{Initial Body Weight}^{1/3}}{\text{Sum (Temperature (}^{o}\text{C) x Days)}}$$

Iwama and Tauz (1981)
Cho (1992)

Growth indice:

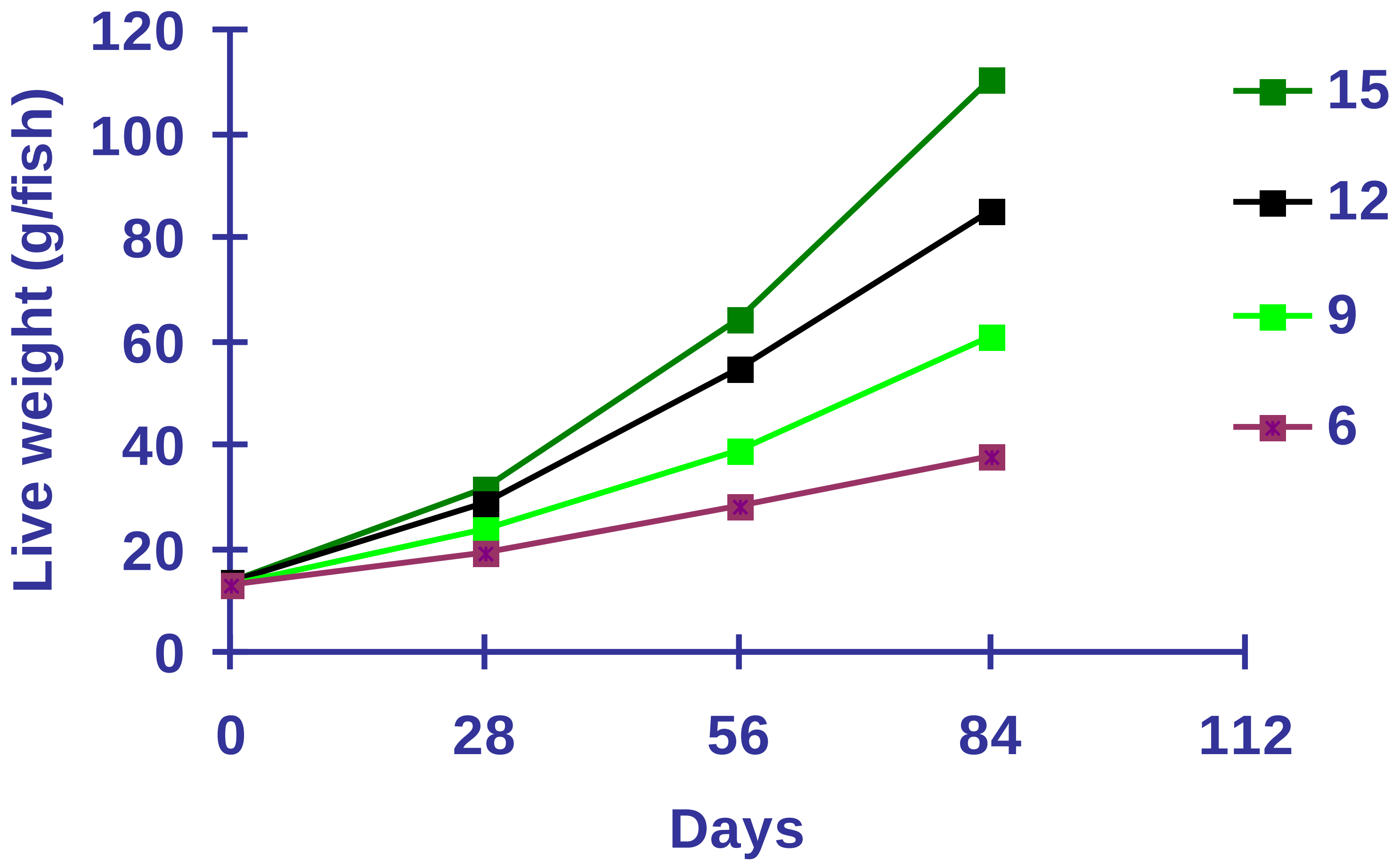
- independent of fish size
- independent of length of time intervals
- independent of water temperature
- dependant of genetics
- dependant of rearing practices, etc.

Rainbow trout fed to near-satiation at reared 8.5°C for 24 weeks

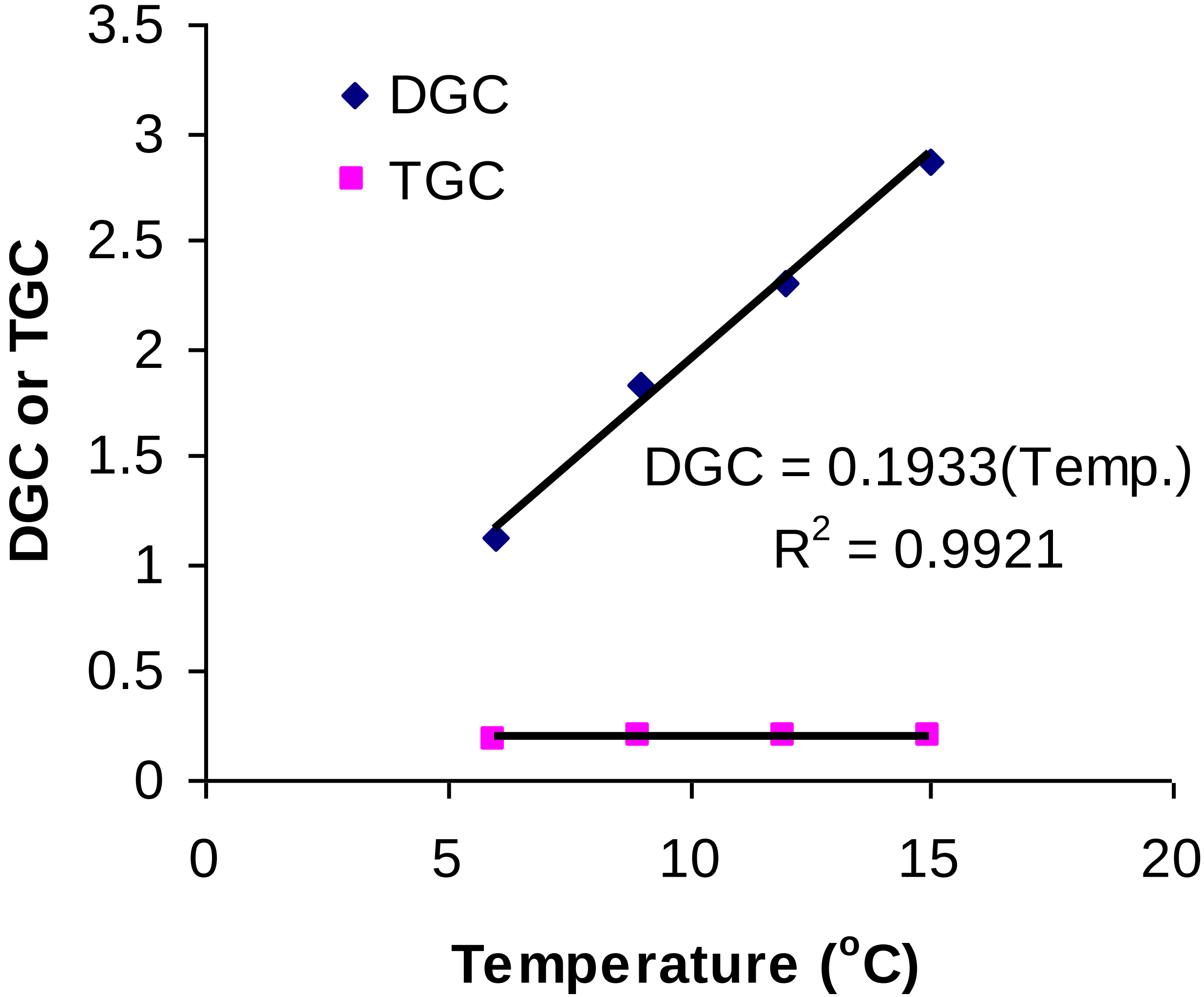


Growth Potential Hypothesis :
Animals seek to a target growth trajectory unless limited by some constraints or modified by interventions

Rainbow trout fed to near-satiation at reared 6, 9, 12 and 15^{o}C for 12 weeks



This rational/predictable growth pattern/trajectory remains fundamentally the same across environmental conditions (within certain boundaries)

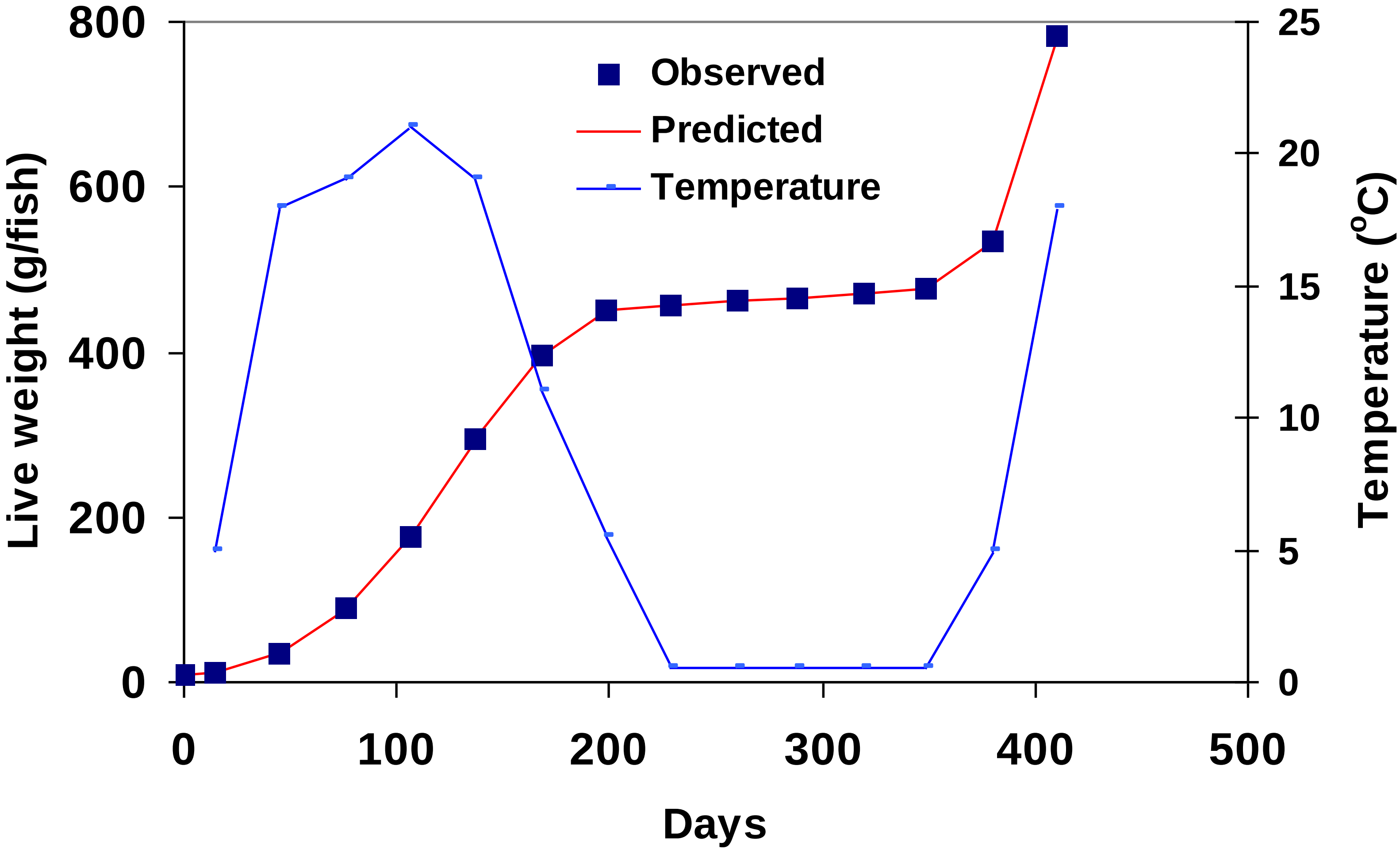


The effects of environmental conditions (e.g. temperature) is also rational/ predictable and can, thus, be described with relative simple mathematics.

Making our way to the field….

Winter on a rainbow trout farm in Canada

Domesticated Rainbow trout
OMNR White Lake Fish Culture Station



Bureau et al. (2000)

Limitations of the TGC Model

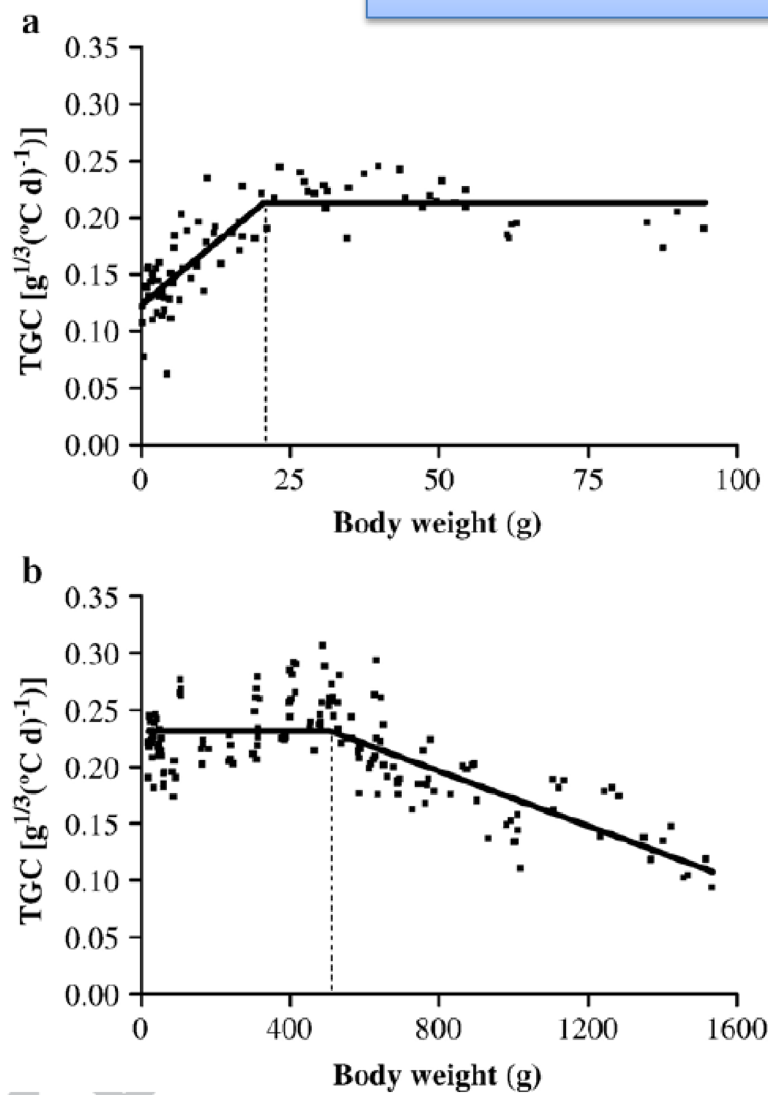


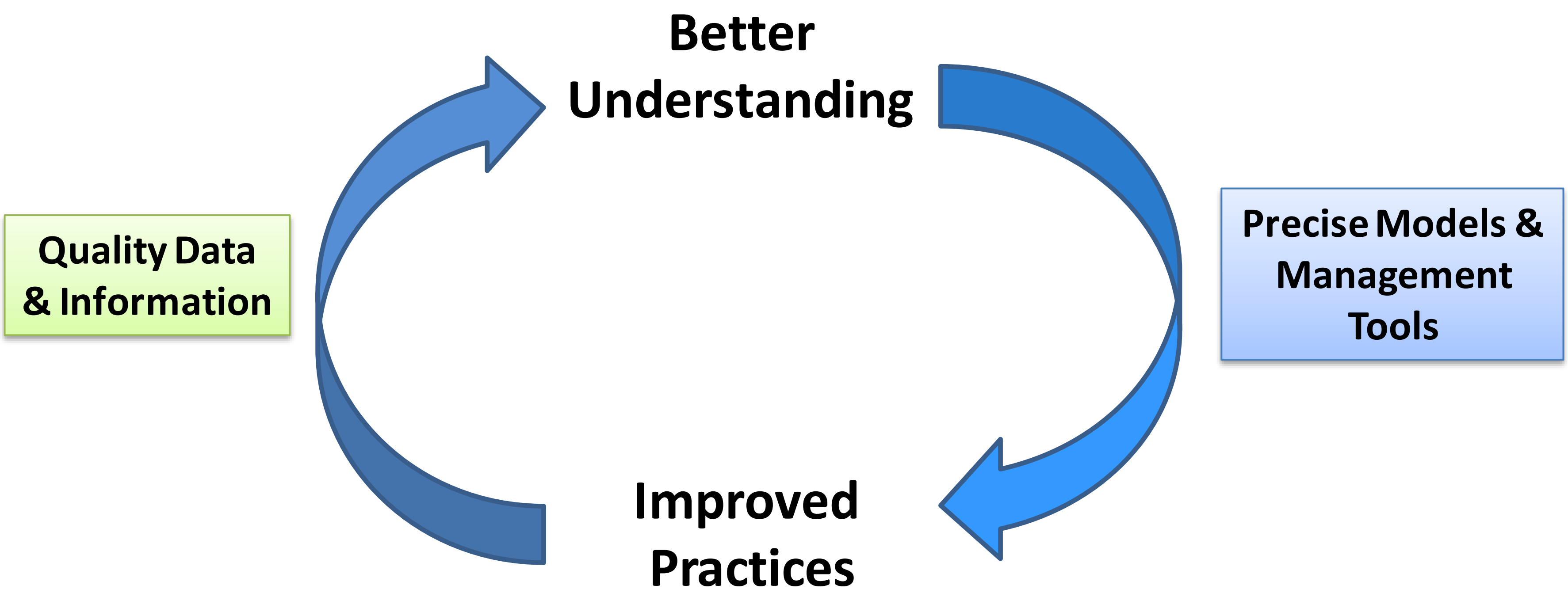
Fig. 2. Piecewise linear analysis of the thermal-unit growth coefficient (TGC) as a function of body weight (BW): (a) BW < 100 g, (b) BW > 20 g. Dotted lines indicate the body weight at breakpoints.

Evidence of three (3) growth stanzas for rainbow trout:

= Need a modification of the TGC model to separate the three stanzas

Dumas et al. (2007)

Continuous Improvement Framework



Using available information in order to determine validity of models and to improve or refine them

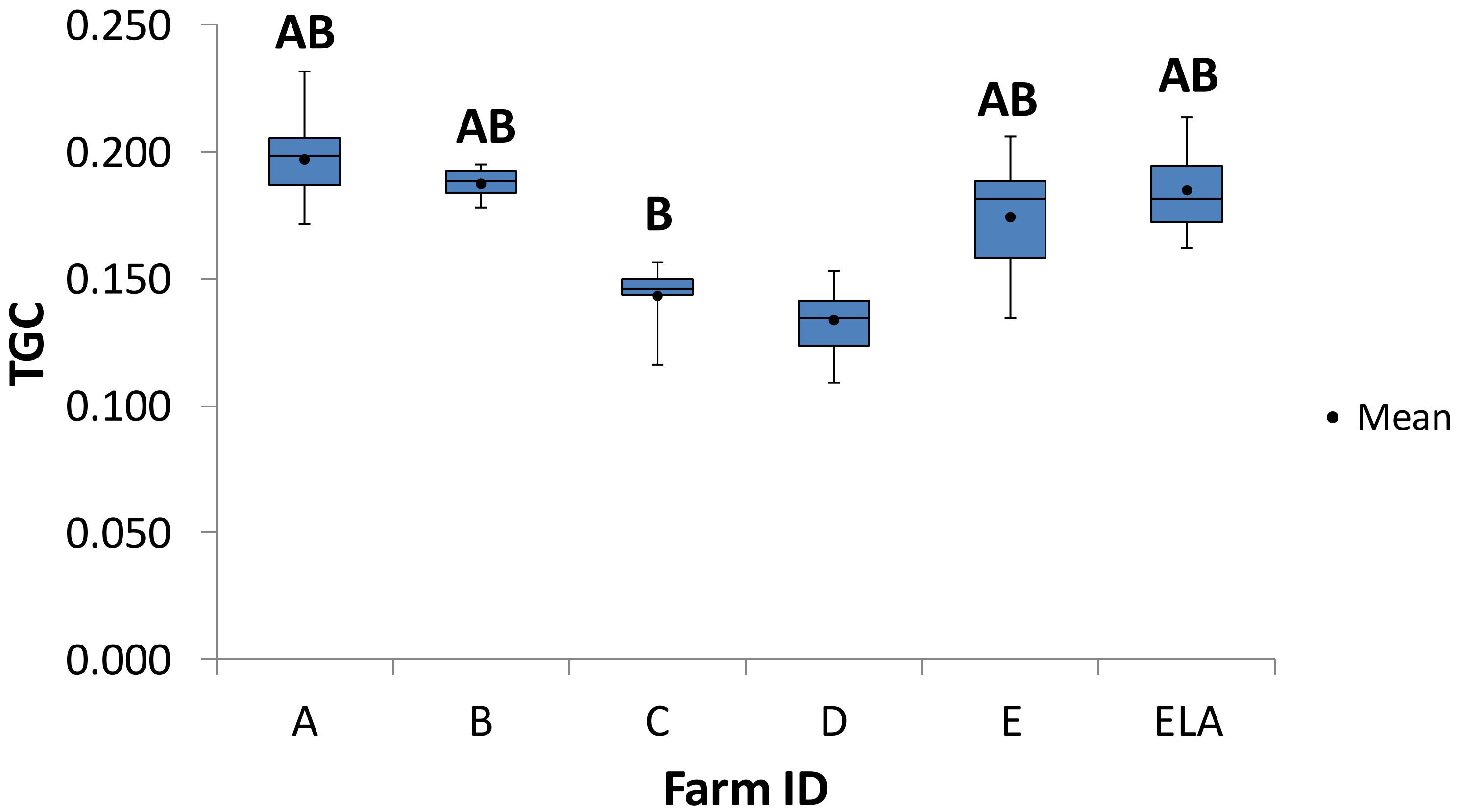
Growth Performance and Feed Conversion Ratio of Commercial Rainbow Trout Farms in Ontario, Canada

Owen Skipper-Horton, Gord Vander Voort, Flavio Schenkel, Dominique P. Bureau
Dept. of Animal and Poultry Science, University of Guelph

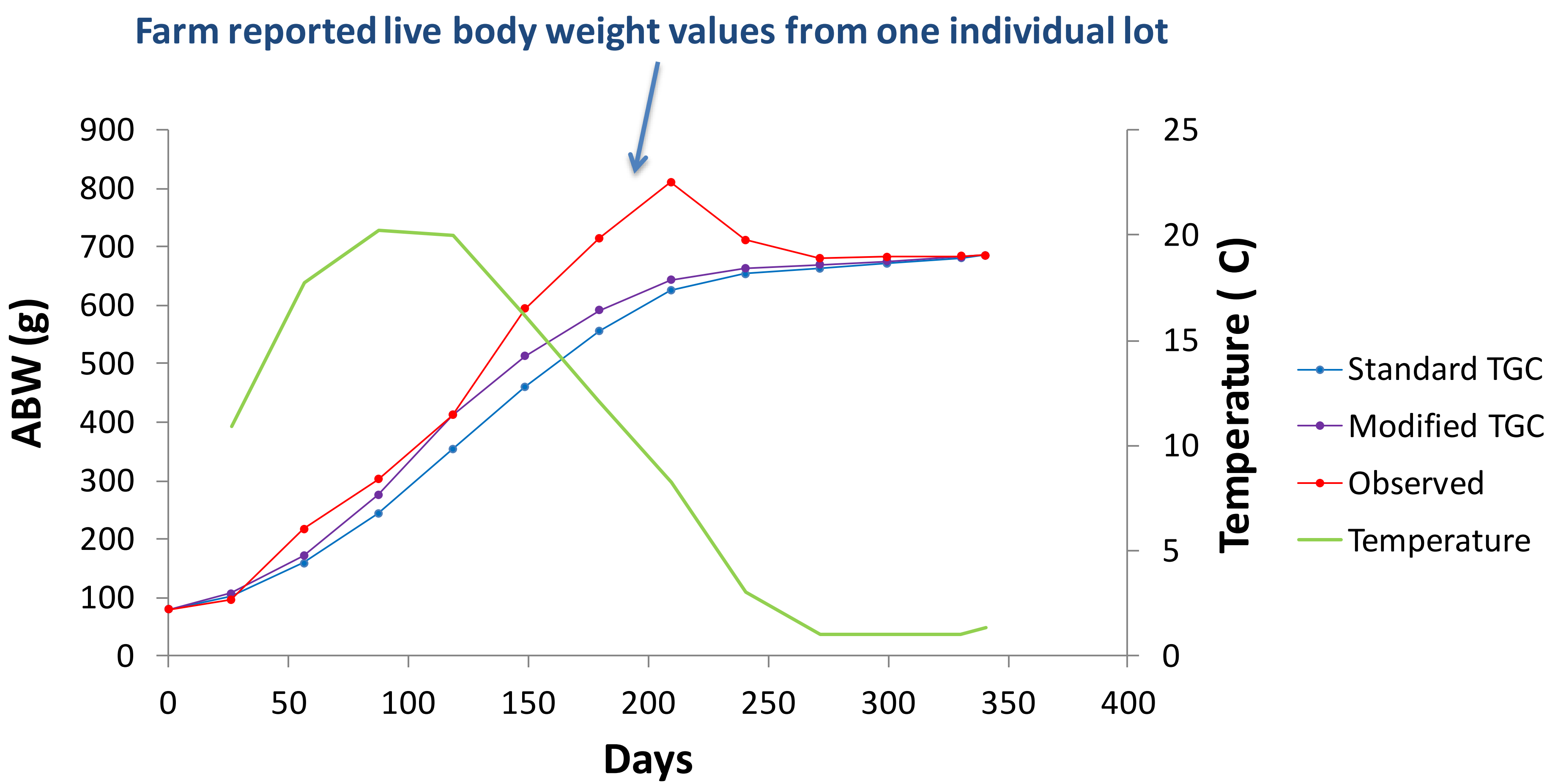
- Results -

Thermal Unit Growth Coefficients (TGC*)

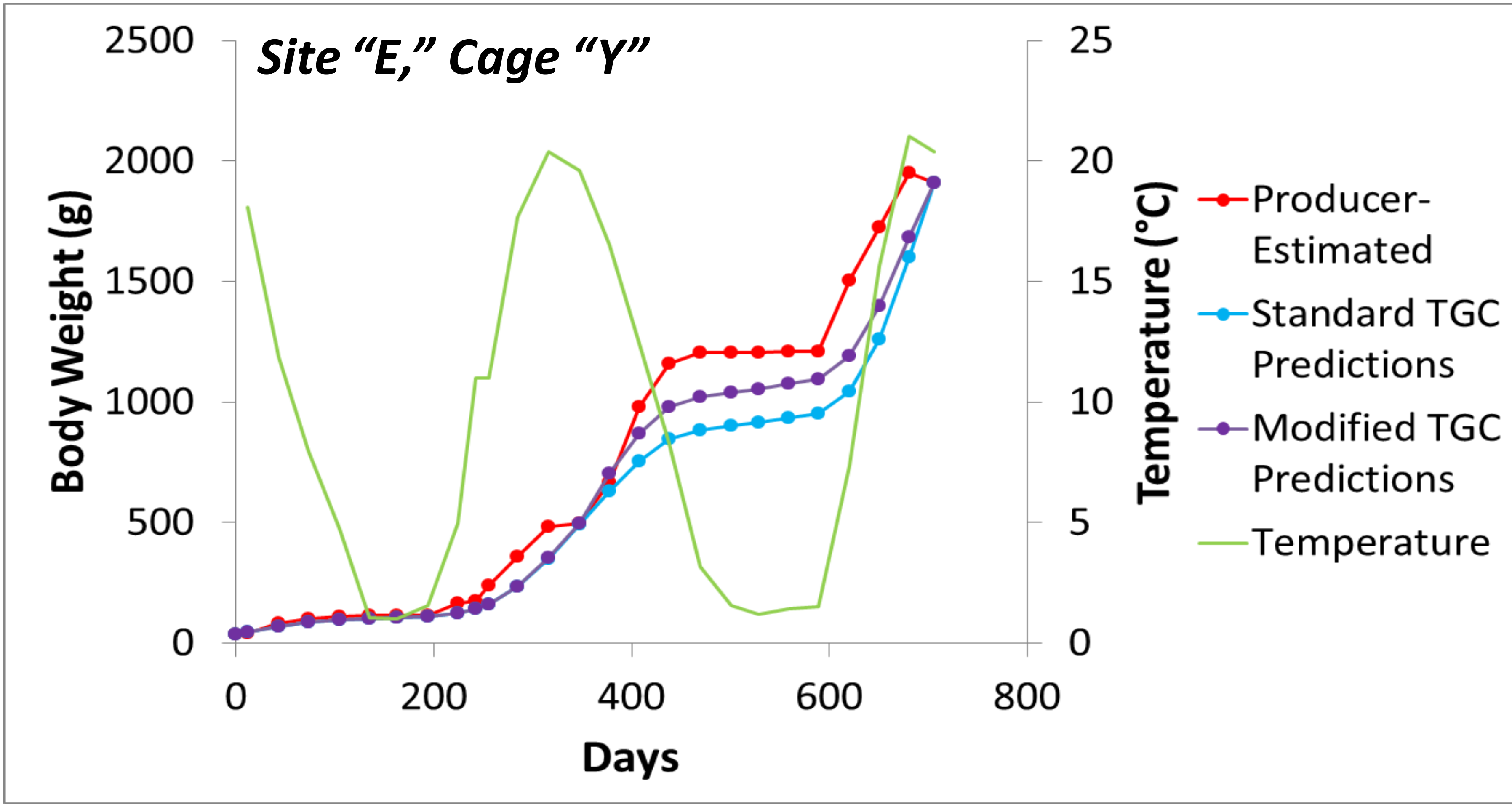
TGC = $(FBW^{1/3} - IBW^{1/3}) / \Sigma$ (temp days)



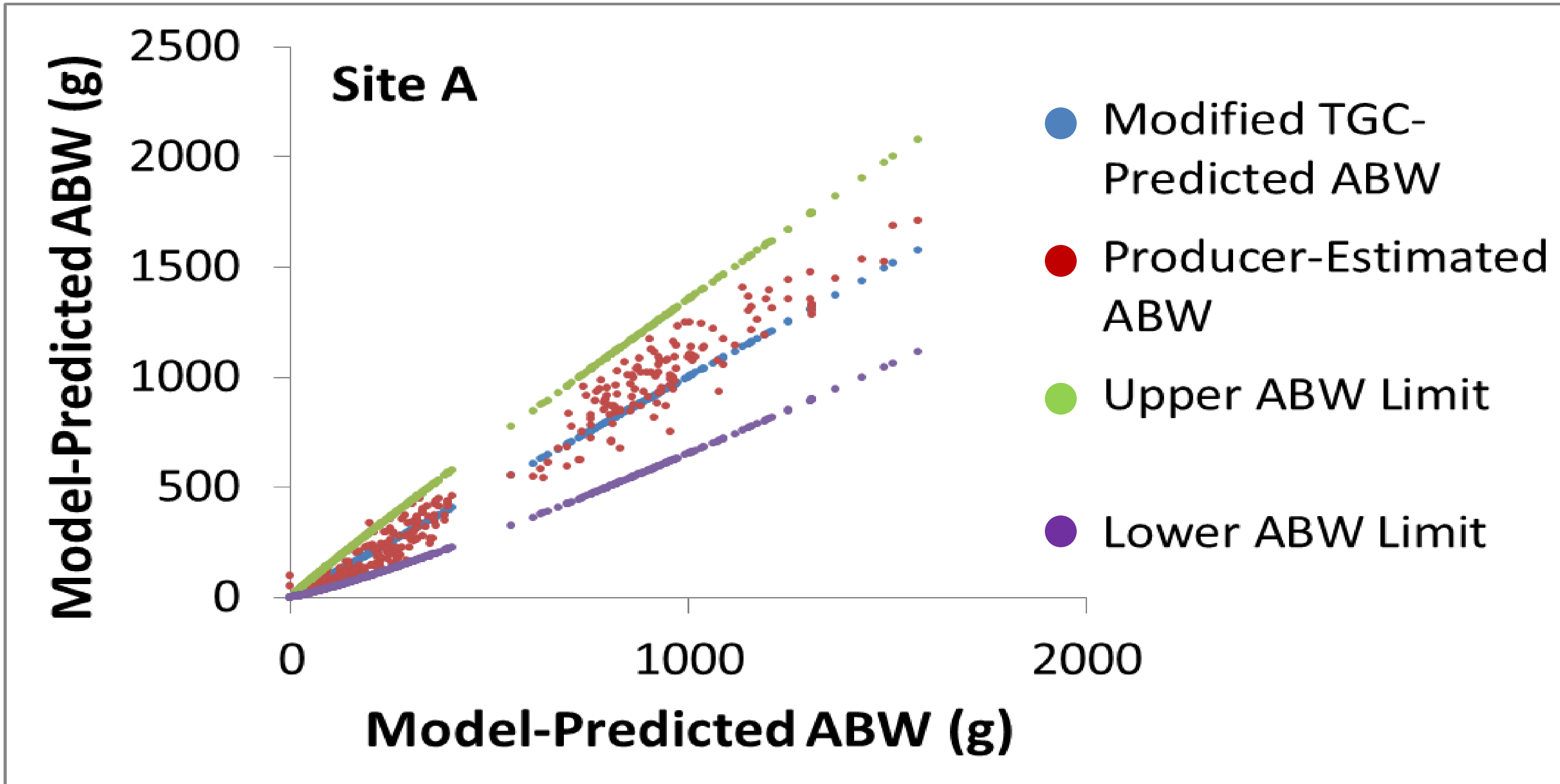
Application to commercial rainbow trout farm data



Farm Body Weight Estimates Relative to Model Predictions



Farm Estimates Appear to Deviate Towards Size of Largest Individuals Within Cages



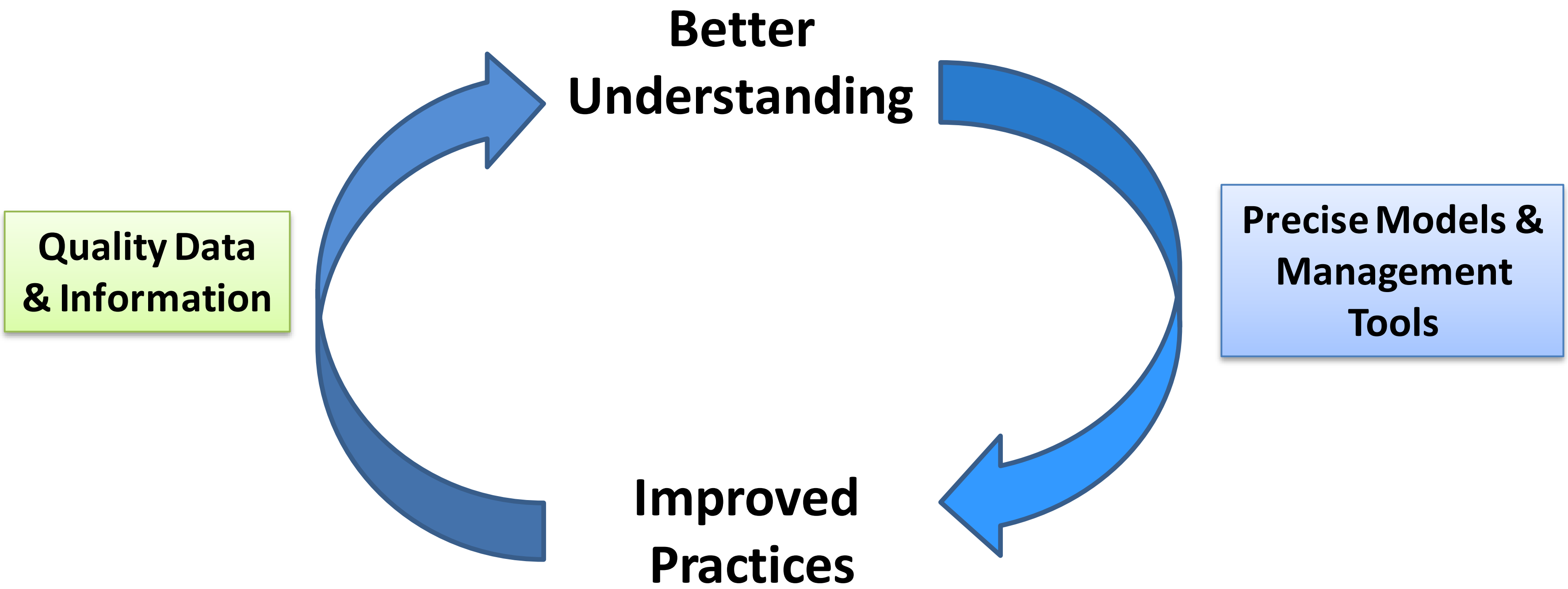
*****Farm-reported estimates of fish weight at different intervals are thus not highly reliable*****

Reliability of Farm Estimates?

- To estimate body weight of fish, most producers use feed enticement and dip-netting
- Typical body weight estimates involve small numbers of fish (e.g. <1% of population)
- Little to no quantification of within-cage size variability

Dip-netting with seine net

Continuous Improvement Framework

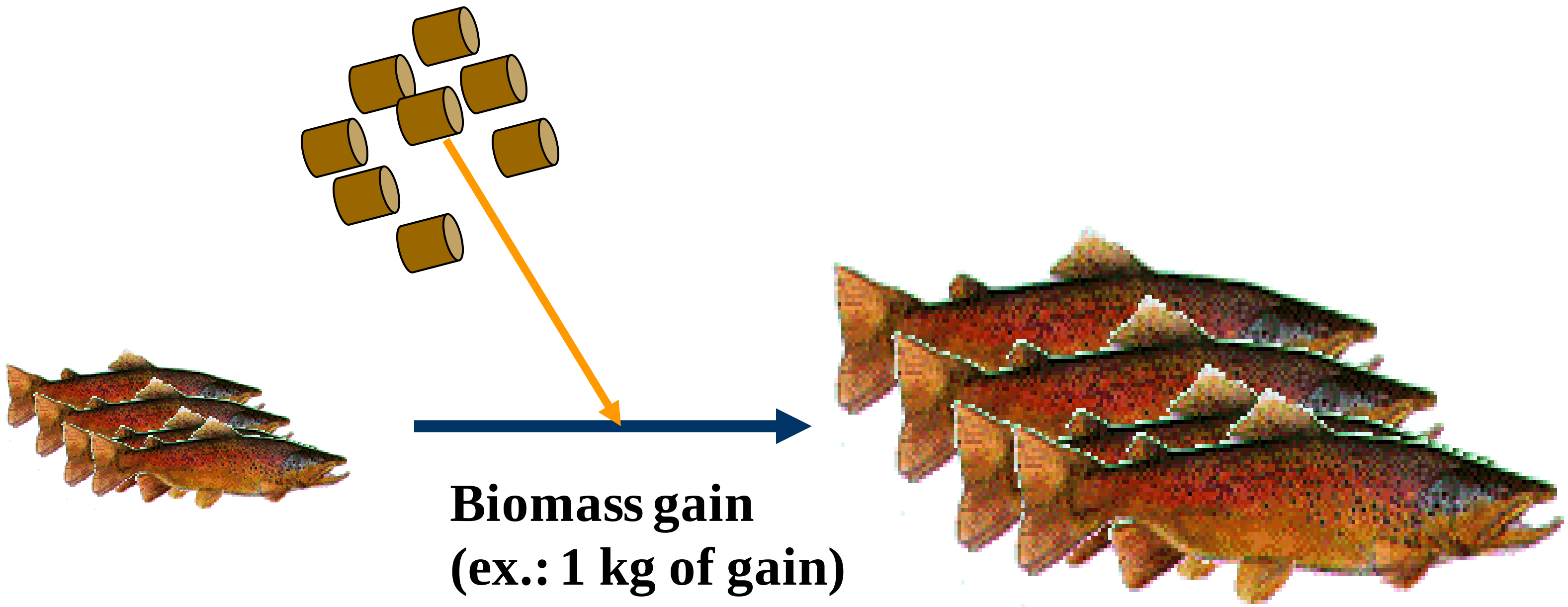


Using available information and modeling allowed us to point out to significant sampling bias by fish producers

Efficiently Conversion of Feed into Fish Biomass and Products

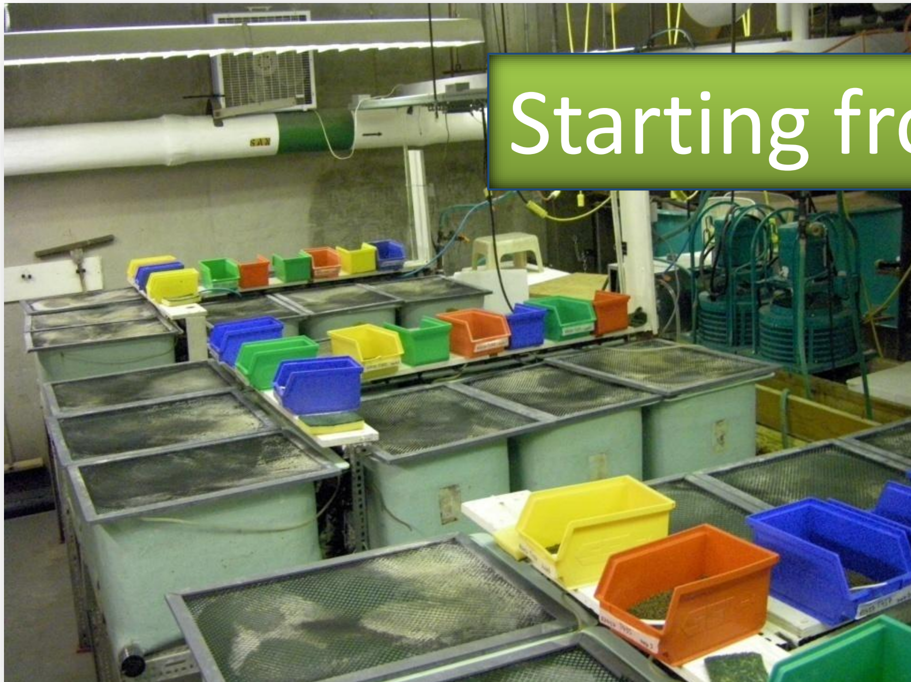
Key Focus of Research Program of Fish Nutrition Research Laboratory

Feed served (ex.: 1 kg of feed)



Biomass gain
(ex.: 1 kg of gain)

Starting from the lab....



The Fish-PrFEQ Bioenergetics Approach (Cho, 1991)

1- Predict or describe growth

Need an appropriate growth model

2- Determine energy gains (RE)

Need information on carcass composition
Carcass gross energy (GE) x Weight gain

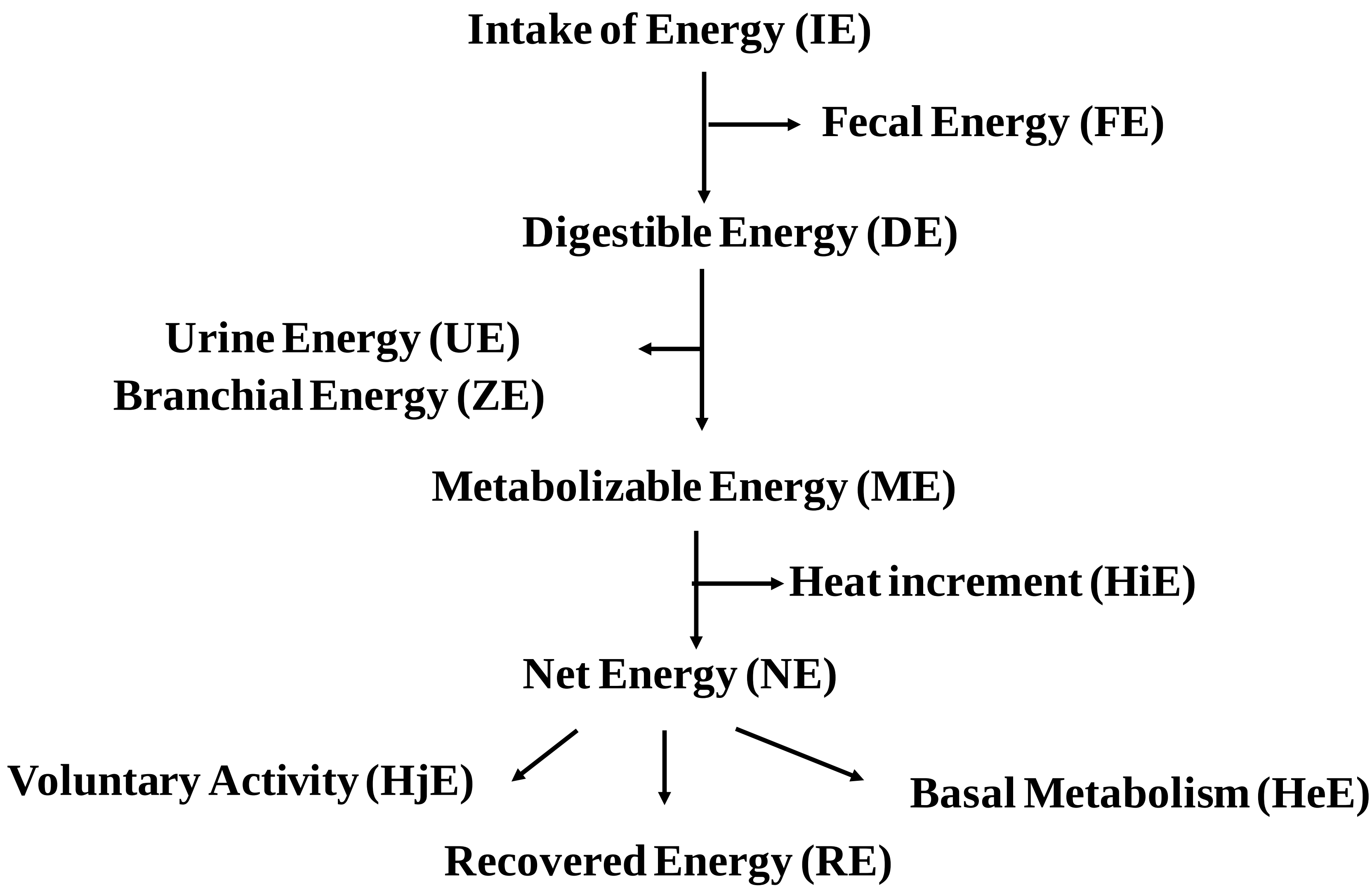
3- Estimate heat and metabolic losses

Maintenance (HeE) + Heat increment (HiE) + Non-fecal losses (UE+ZE)

4- Digestible energy requirement = sum

$$DE = RE + HeE + HiE + (UE+ZE)$$

Bioenergetics Scheme (NRC-NAC, 1982)



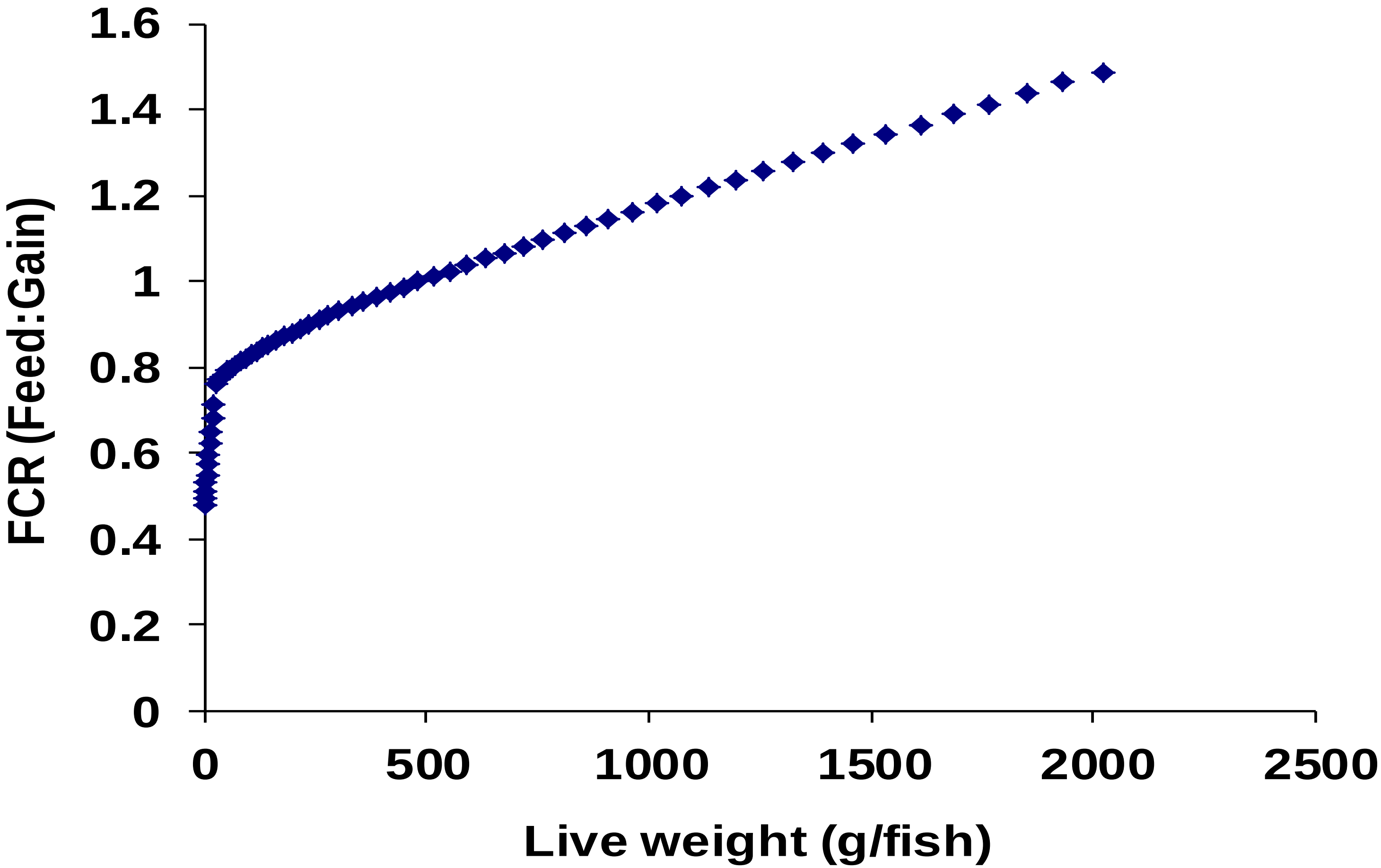
The Fish-PrFEQ Bioenergetics Model

Digestible Energy Requirement/ Digestible Energy of Feed

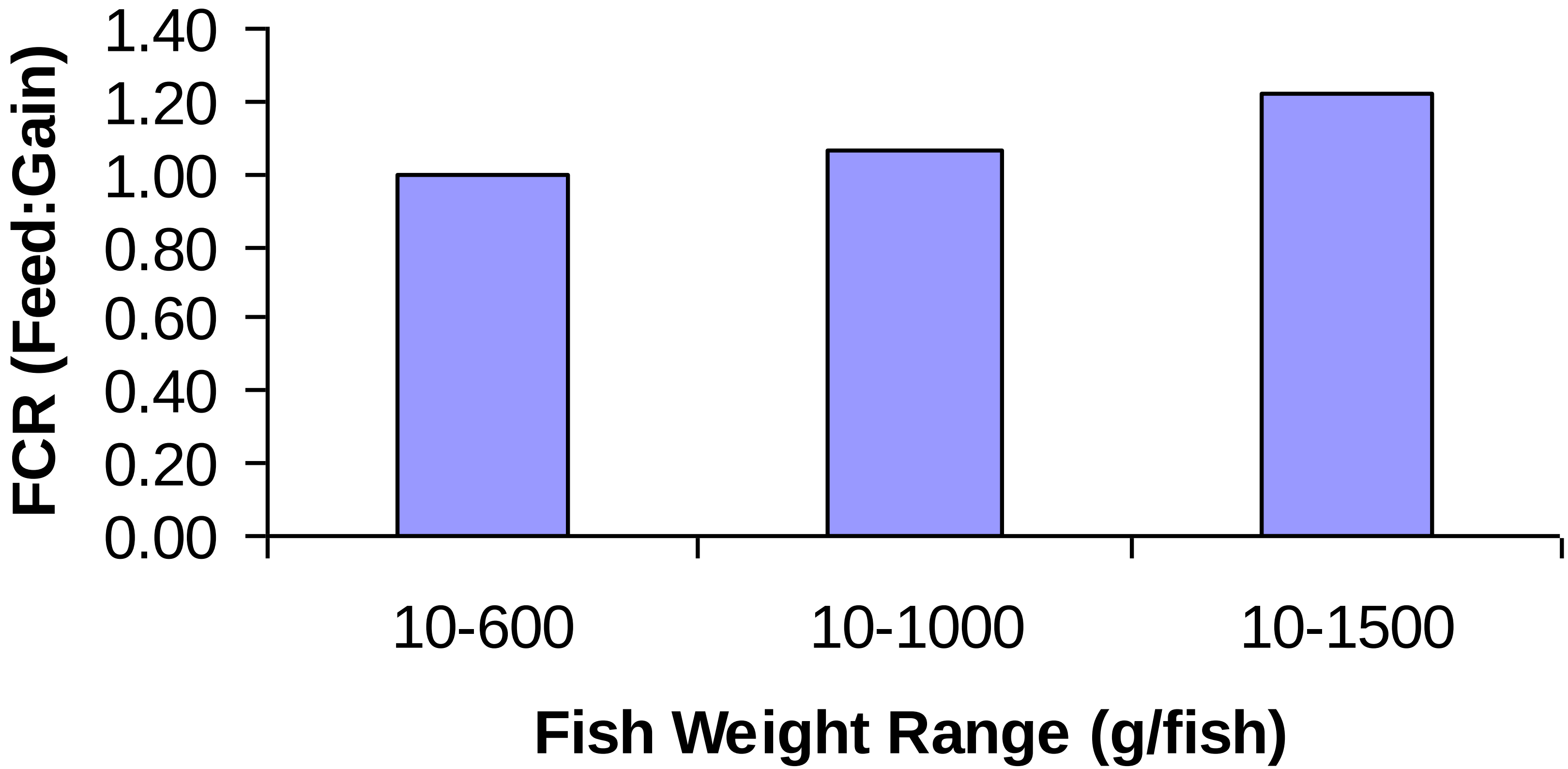
Theoretical Feed Requirement (per Unit of Weight Gain)

Theoretical Feed Conversion Ratio

Prediction of FCR of rainbow trout of increasing weight using a model developed by the UG/OMNR Fish Nutrition Research Laboratory



Expected FCR of fish reared to different harvest weights

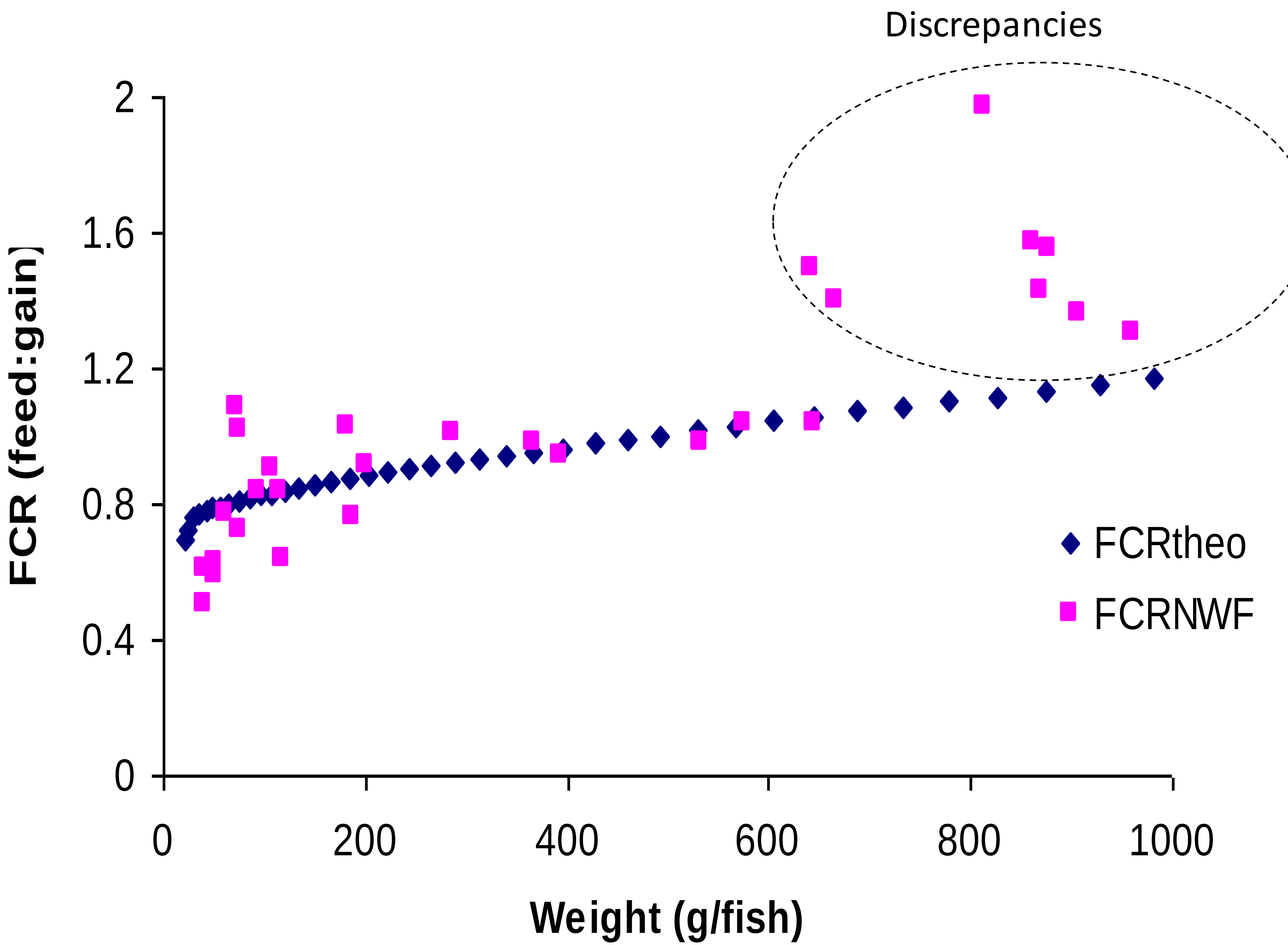


Feed: 37% DP, 20 MJ DE

To the field…

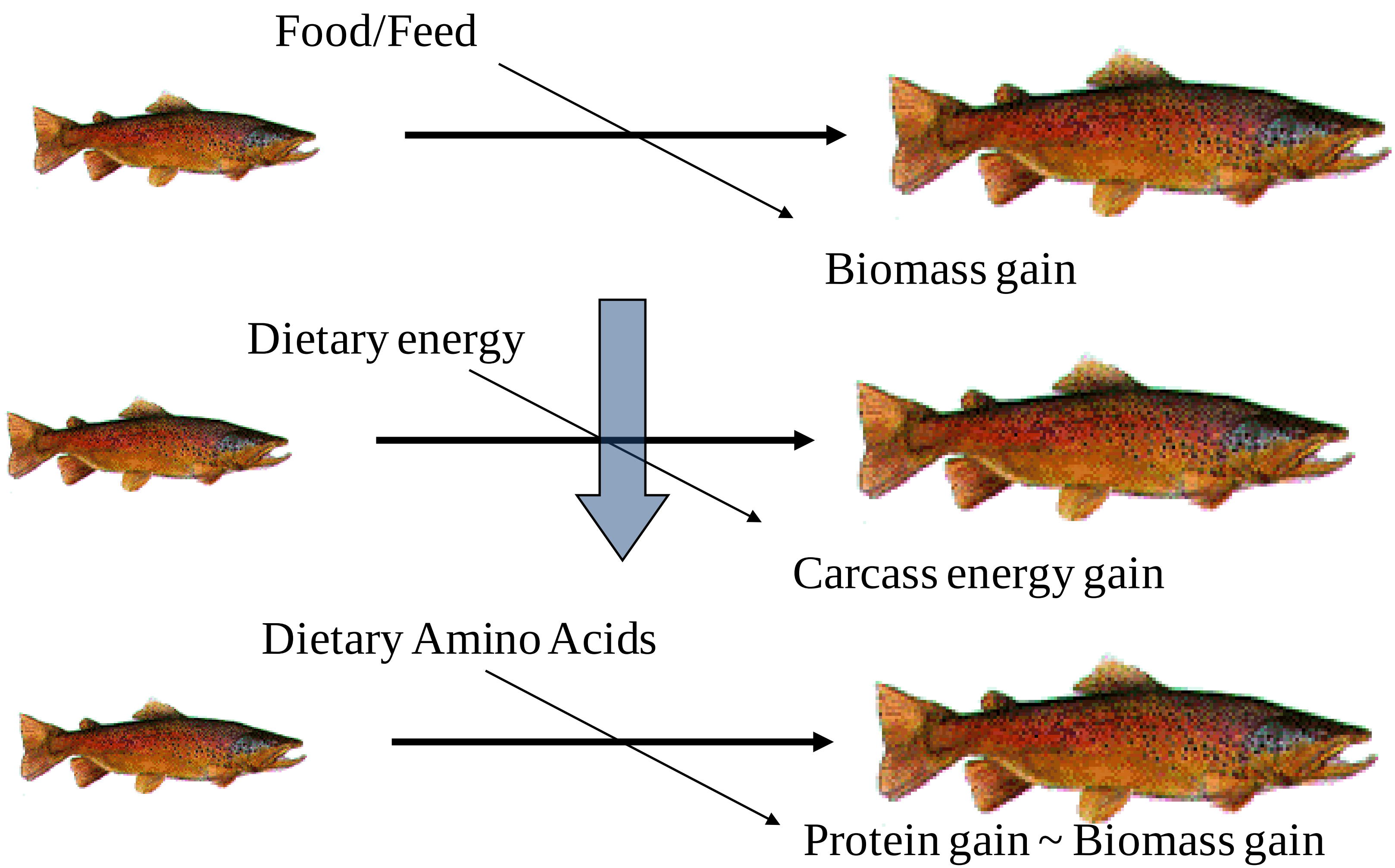
Feeding Time on Cage Rainbow Trout Culture Operation

Model Predictions vs. Farm Data

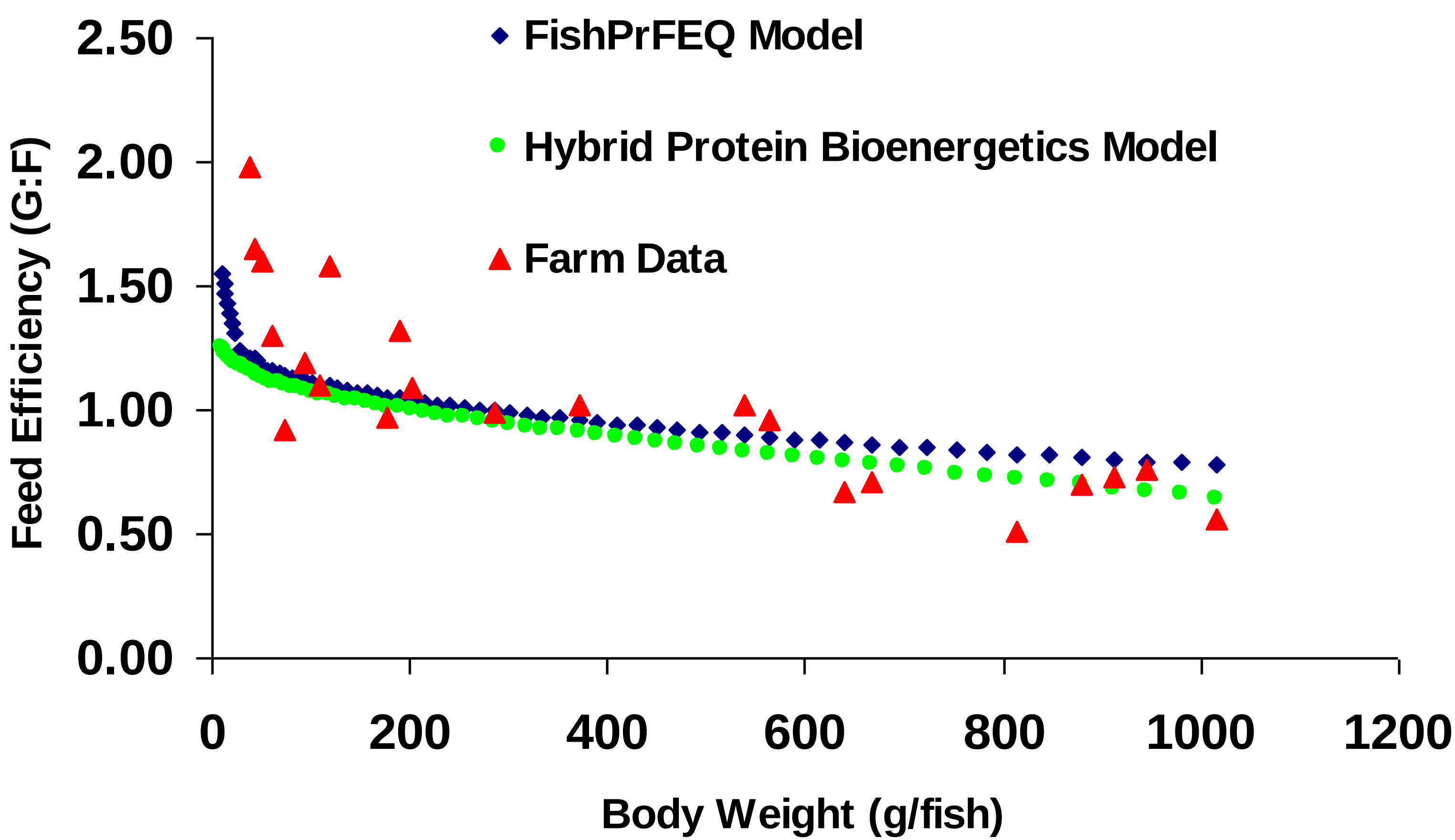


FCR Data courtesy of NorthWind Fisheries & Gregor Reid

Evolution of Feed Utilization Models



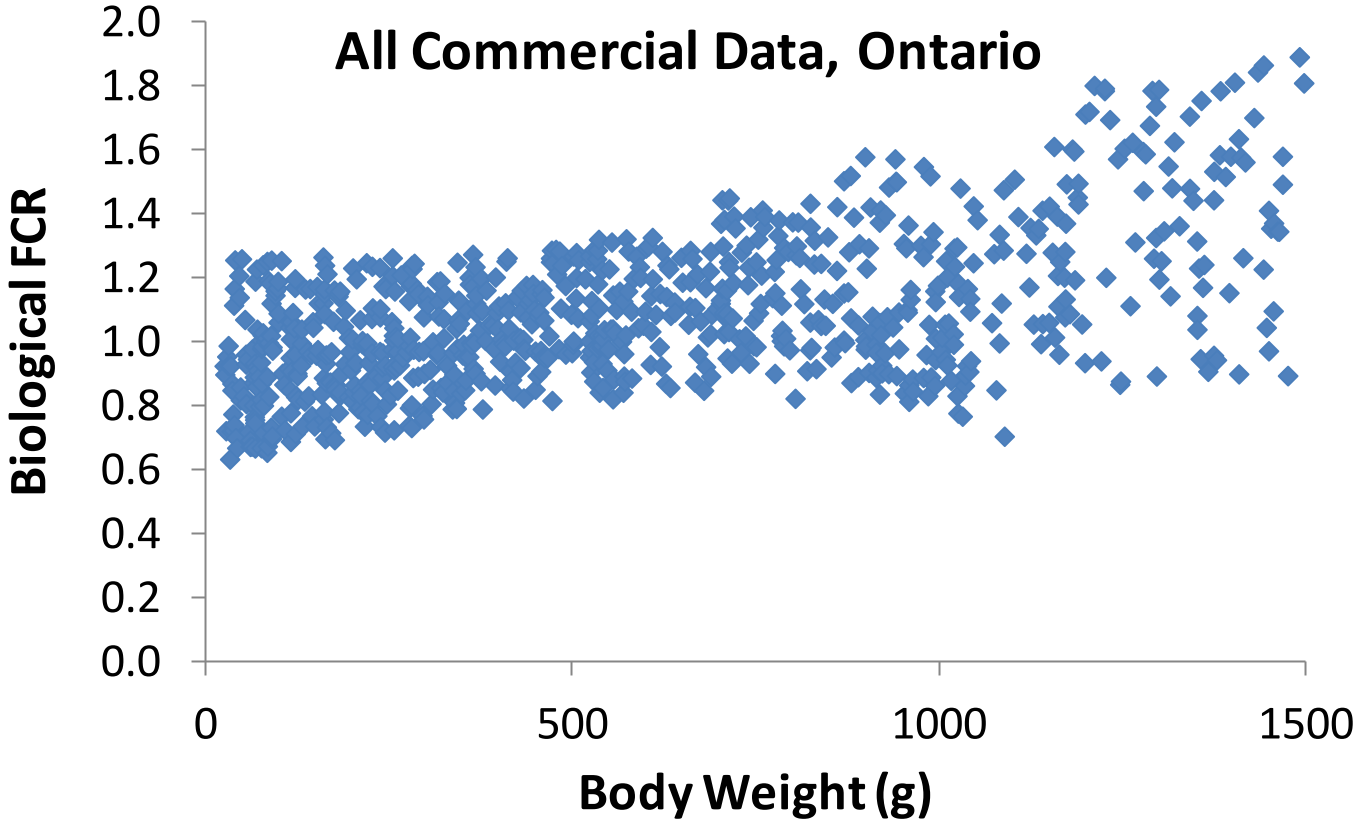
Model Simulations vs. Farm Data



Bureau and Hua (2006)

– Results –

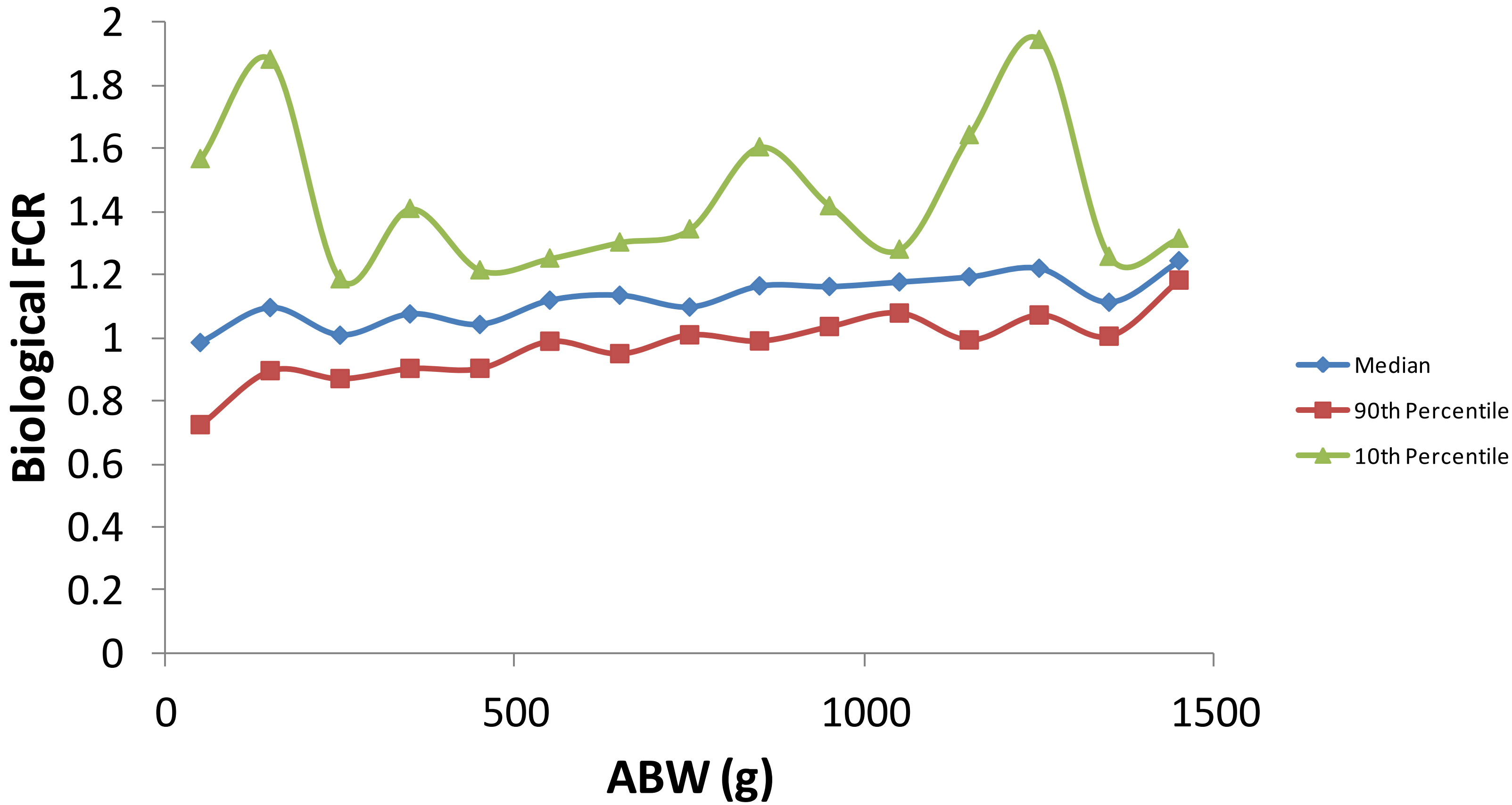
FCR vs. BW



- Data suggests increase in feed conversion ratio as fish weight increases
- Consistent with results from controlled research trials and model predictions

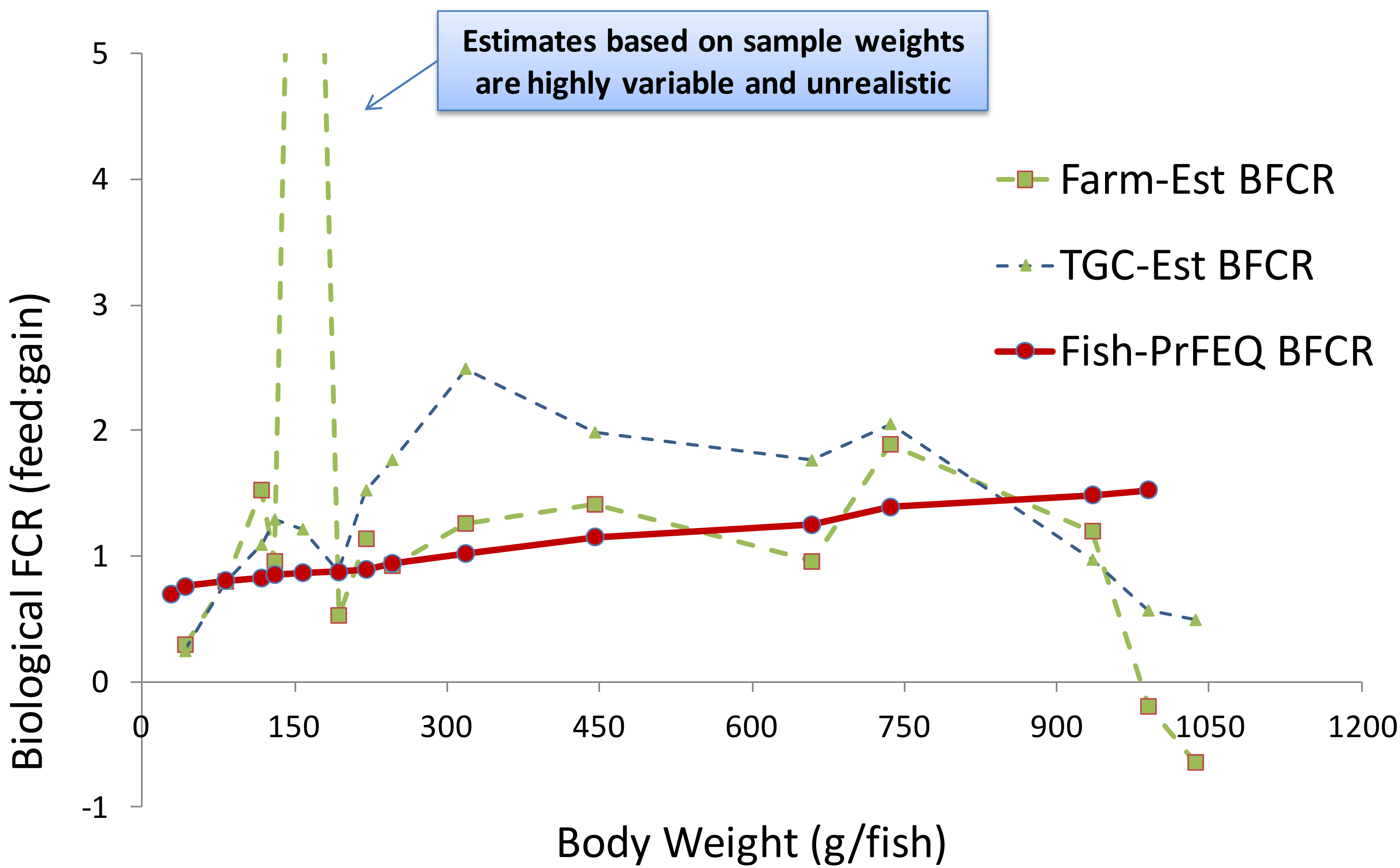
The Power of Combining Real Production Data and Model Simulations

Ex: FCR vs. Average Body Weight (ABW)



- Data suggests increase in feed conversion ratio as fish weight increases
- Consistent with results from controlled research trials and model predictions

Biological FCR: Farm Estimates vs. Model Estimates (Interval Basis)



Conclusion

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" !!!

Acknowledgements

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United Soybean Board
AquaNet, Canadian Network of Centres of Excellence
Martin Mills
Aqua-Cage Fisheries Ltd.
Jefo Nutrition