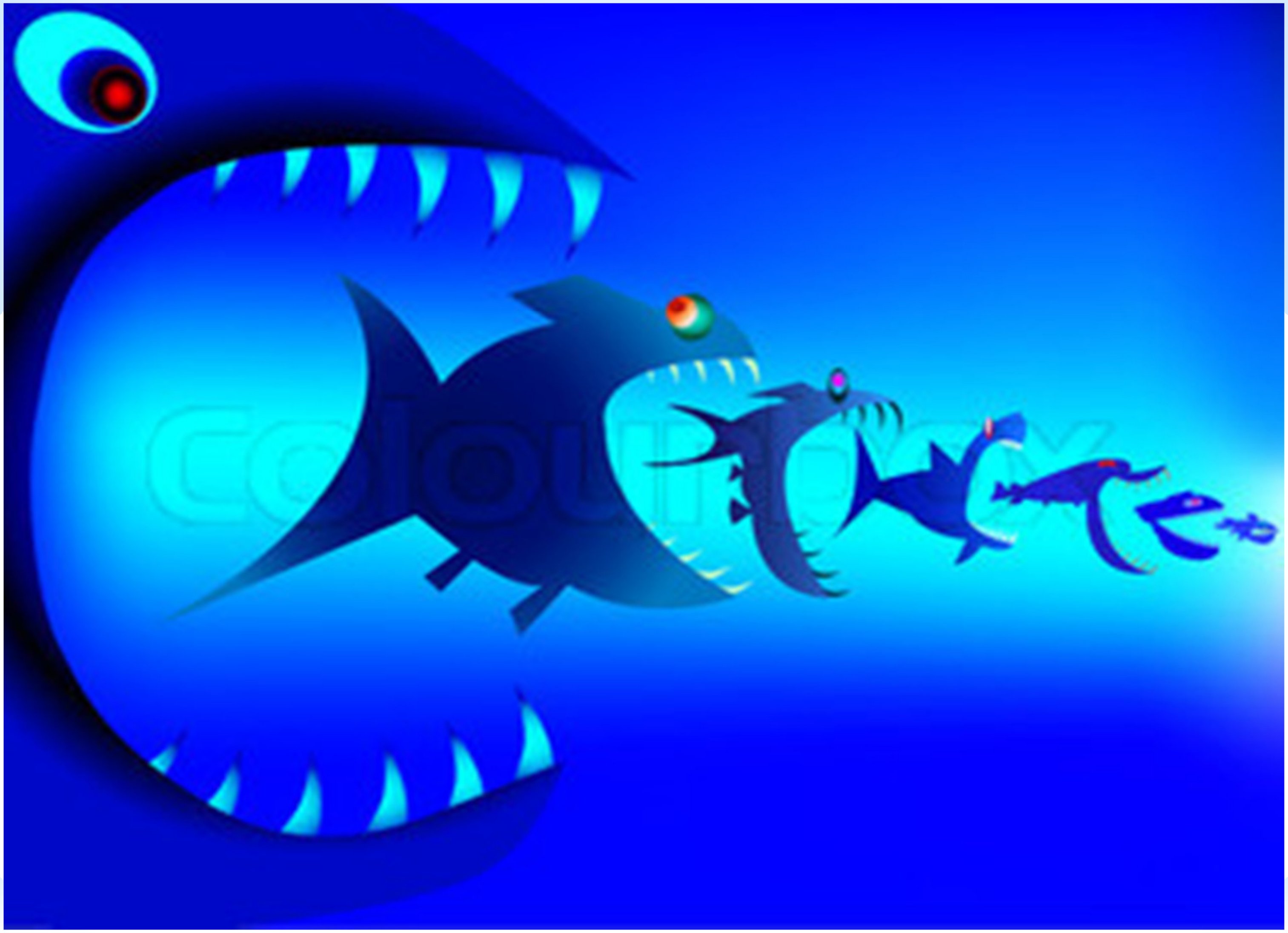
Sustainable Fish Diets for the 21st Century using Soybean Protein

Paul B. Brown, Purdue University, West Lafayette, Indiana, USA pb@purdue.edu

*Introduction

* If you want to grow an animal, you must provide adequate food resources.
* Inadequate food intake negatively affects growth, health and reproduction, and increases cost of production
* Feed costs are significant
* Are all nutritional requirements for fish the same? Is it reasonable and appropriate to develop species specific diets?
* Increased aquacultural production placing significant demand on fish meal and oil supplies



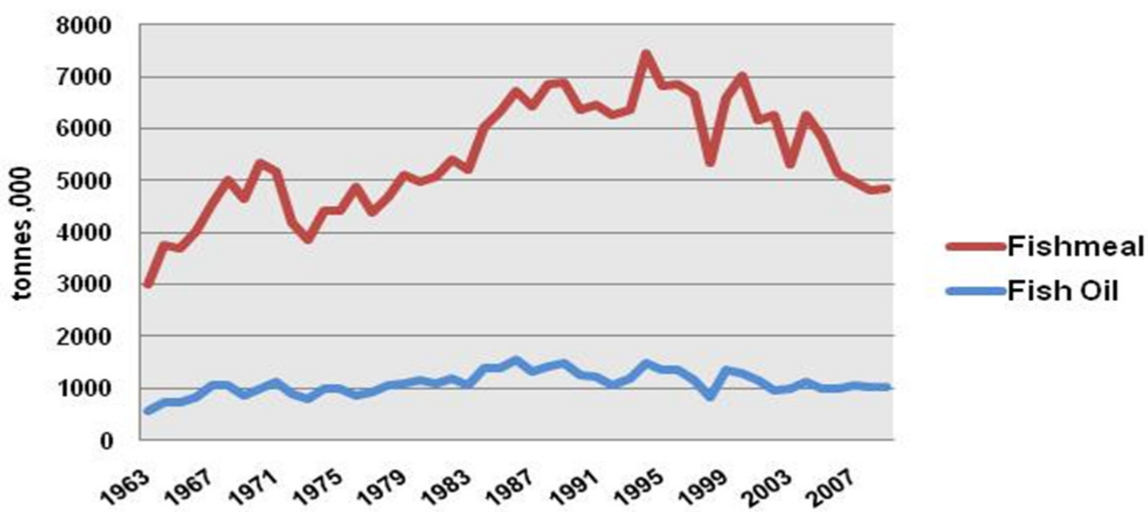
*Ingredients

* Fish meal and oil

* 1960s – Ingredient for swine and poultry feeds
* 1980s – Poultry feed (50%), aquaculture 10%
* 2010 – Aquaculture demanding 73%, poultry 5%, swine 20%
* J. Shepard, past Director General, International Fishmeal and Fishoil Organisation (IFFO)

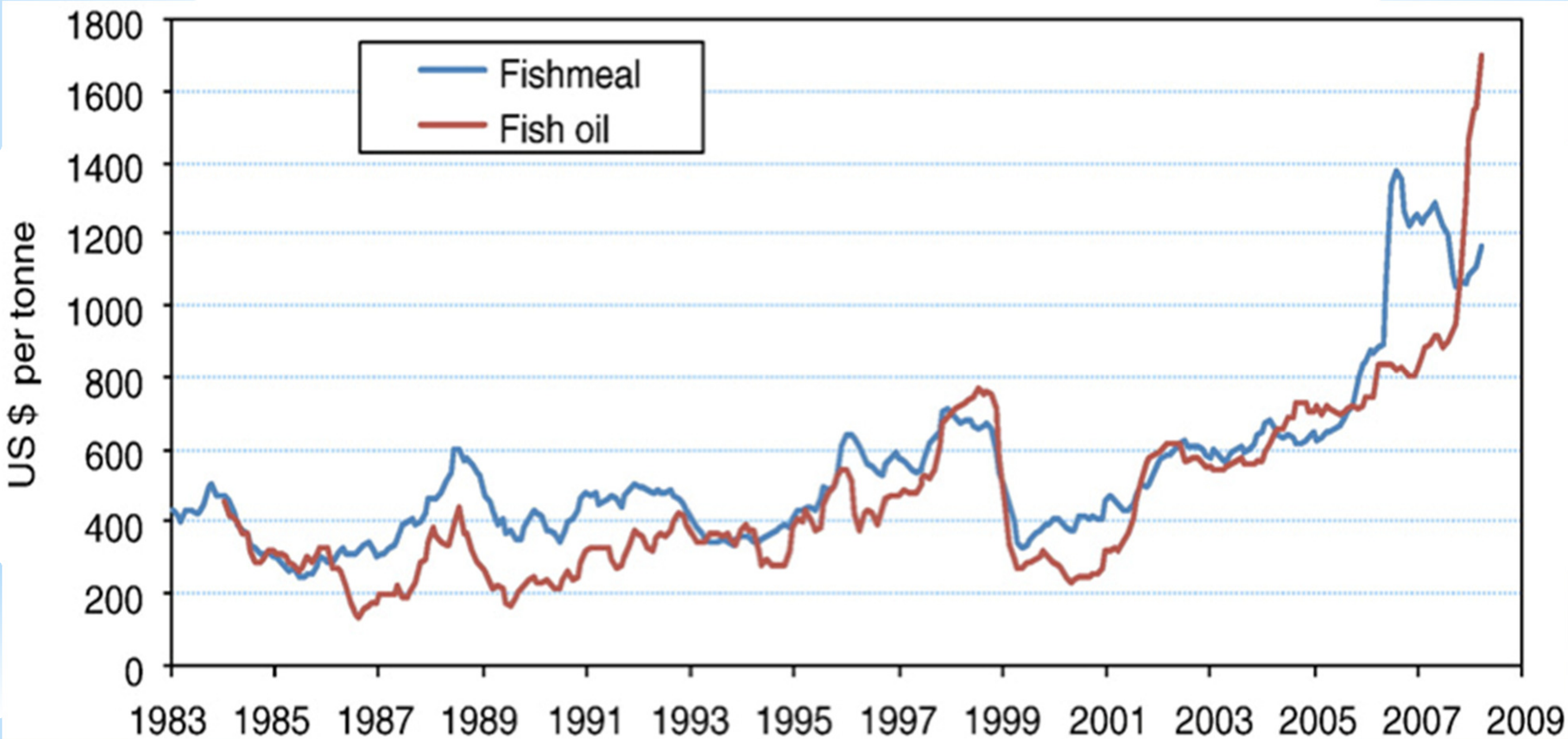
*Ingredients

* Sources of fish meal and oil – sardines, menhaden, anchovy, mackerel, capelin, herring
* IFFO - http://www.iffo.net/default.asp?contentID =718



*Ingredients

* Tacon and Metian, 2008, Aquaculture 285:146-158



*Summary

* Primary ingredient is at maximum sustainable yield – supply is unlikely to increase
* Demand for that ingredient is increasing
* Price is increasing

*Ingredient substitution

- *Candidate replacement plant feedstuffs
  - *Soybean meal, canola (rapeseed) meal, lupin meal, pea meal, wheat gluten, cottonseed meal, sunflower seed meal, safflower seed meal, sesame seed meal, linseed meal, corn gluten meal, whey, groundnut meal, brewer’s grains and yeast, distiller’s dried grains
  - *Protein concentrates and isolates (soybean, pea, lupin, potato, whey, alfalfa, rice, etc.)

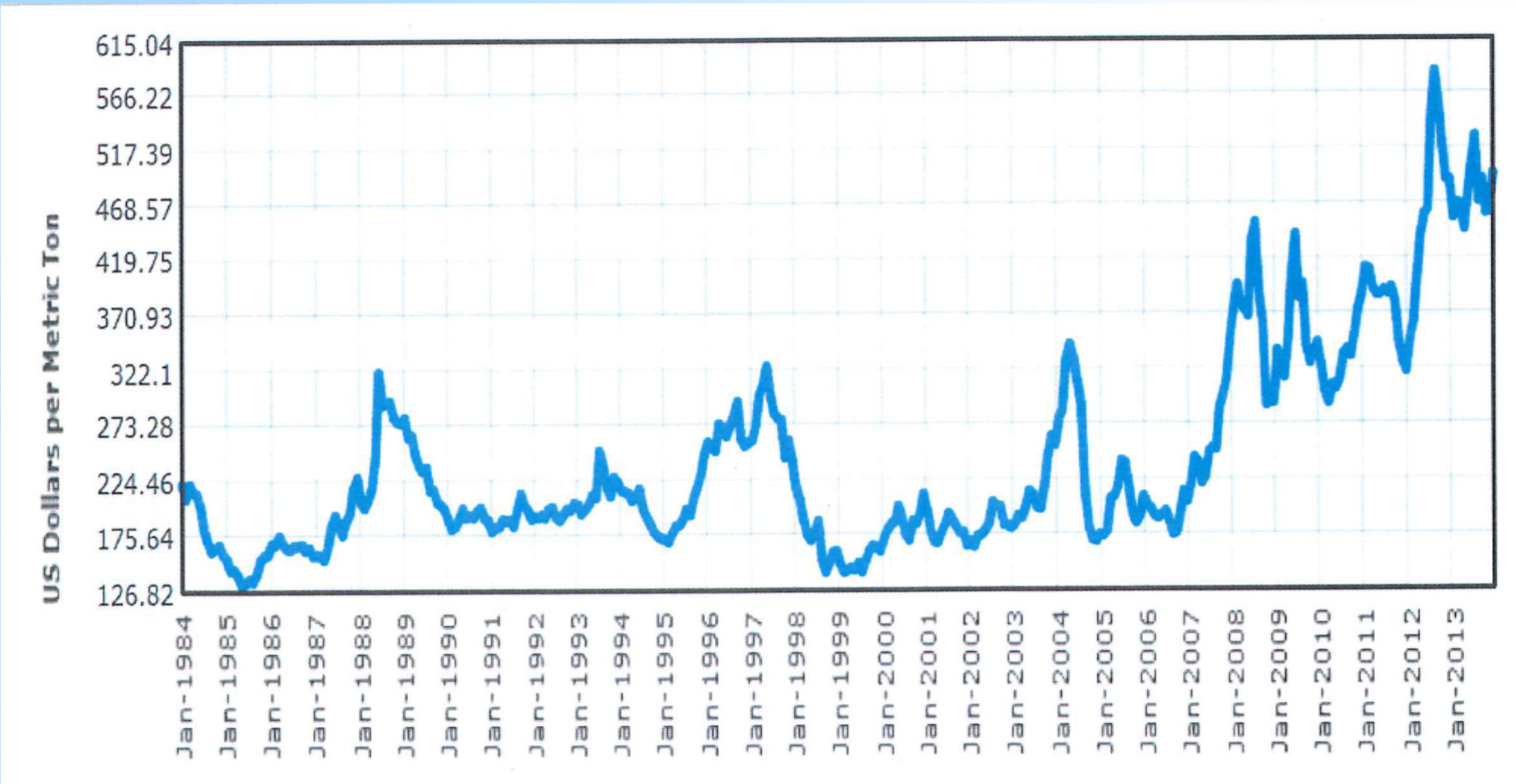
*Ingredient substitution

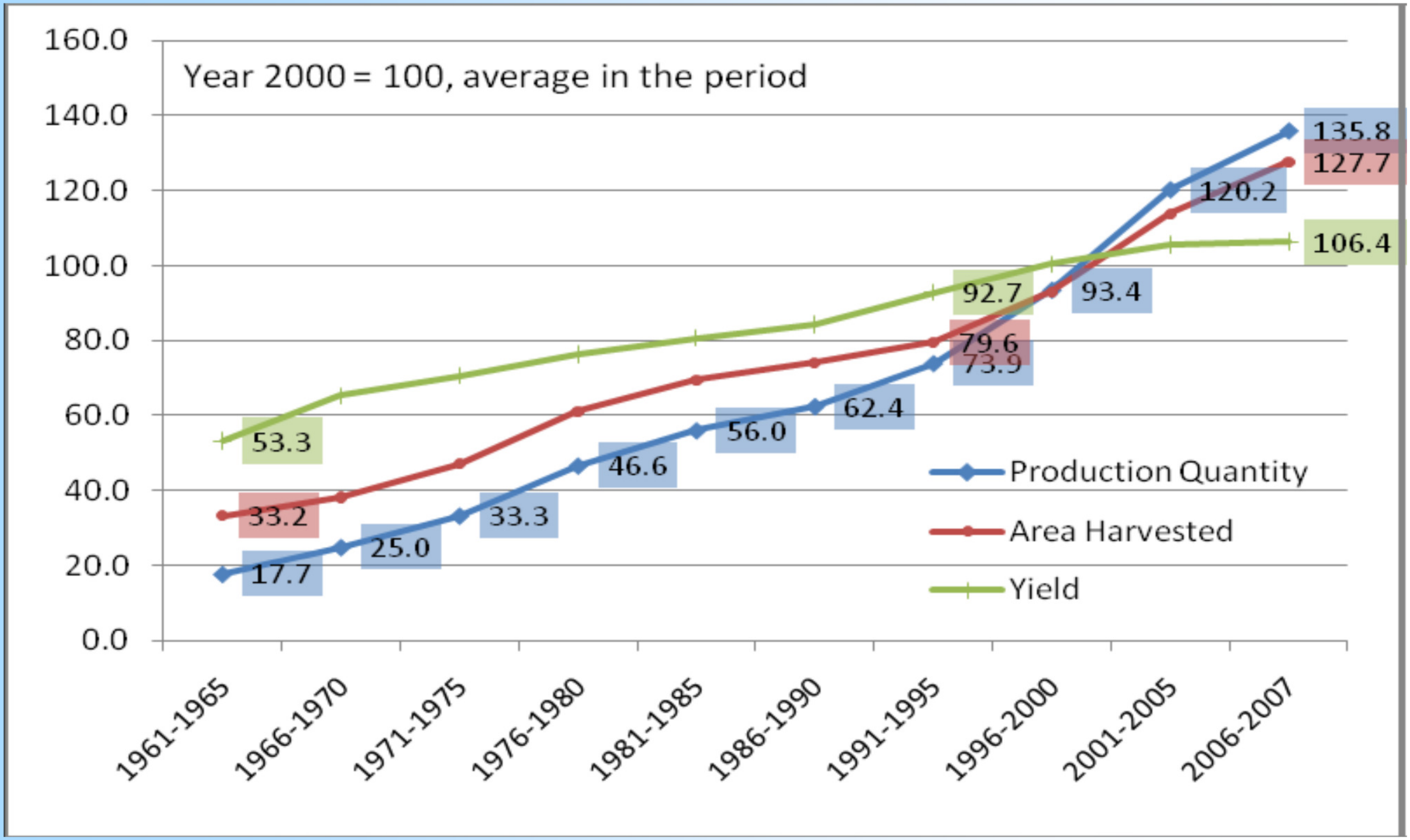
* Candidate replacement plant feedstuffs

* Global production (2011, mmt, UNFAO)

* Soybeans	260.9
* Oil palm	233.8
* Seed, cotton	77.3
* Rapeseed	62.4
* Coconut	59.2
* Cotton	48.8
* Sunflower	40.2
* Groundnuts	38.6
* Palm kernel	12.9
* Peas, dry	9.6
* Sesame seed	4.1
* Castor oil seed	2.7
* Linseed	1.6
* Lupins	1.1
* Safflower	0.6

*Soybean meal prices - 1984-2014




Year 2000 = 100, average in the period
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
135.8
127.7
120.2
106.4
92.7
93.4
79.6
73.9
62.4
56.0
53.3
46.6
33.2
33.3
25.0
17.7
Production Quantity
Area Harvested
Yield
1961-1965
1966-1970
1971-1975
1976-1980
1981-1985
1986-1990
1991-1995
1996-2000
2001-2005
2006-2007

*Soybean Protein

- Protein feedstuffs are key
- Optimal dietary crude protein for fishes is >28% of the diet, with many values in the 40-50% range
- Protein feedstuffs with potential have greater than 30% crude protein
- Isonitrogenous replacement of fish meal with test feedstuff, typically with little understanding of nutritional requirements for target species

* Mineral availability

* Phosphorus in plant feedstuffs can bind other minerals and lead to mineral deficiencies
* Initial evaluation of SBM in diets for hybrid striped bass indicated maximum level of incorporation of 20% of the diet.
* Subsequent study using improved mineral premix indicated HSB were tolerant of up to 40% SBM in the diet.

* Brown et al. 1997

*Essential amino acids

* Factors that may contribute to limited use
  * Nutritional deficiencies – most recent NRC Nutrient Requirements of Fish and Shrimp (2011) lists optimal dietary crude protein concentrations for 21 species (18 fish and 3 shrimp), estimates for probably 100 other species
  * Quantified essential amino acid concentrations (EAA)
    * Lysine – 21 species, 1.2-3.3% of diet
    * Methionine – 16 species, 0.4-1.5% of diet
    * Threonine – 12 species, 0.5-1.8% of diet
  * All ten EAA requirements quantified for 6 species

*Essential amino acid supply

* Essential amino acid requirements – hybrid striped bass
  * Arginine 1.0 -1.5%
  * Lysine 1.4%
  * Methionine 0.7%
  * Methionine + cyst(e)ine 1.1%
  * Phenylalanine 0.9%
  * Threonine 0.9%
  * Tryptophan 0.3%
  * Histidine 0.5%
  * Leucine 1.5%
  * Isoleucine 0.9%
  * Valine 0.8%
  * Twibell et al. 2003. Aquaculture Nutrition 9:373-381.

*Micronutrients

* Essential amino acid requirements – yellow perch
  * Arginine 1.4%
  * Methionine 1.1%
  * Methionine + cyst(e)ine 0.9%
  * Lysine 3.0%
  * Phenylalanine 1.6%
  * Threonine 1.6%
  * Tryptophan 0.3%
  * Histidine 0.5%
  * Leucine 1.5%
  * Isoleucine 0.9%
  * Valine 0.8%
  * Hart et al. 2010. Aquaculture Nutrition 16:248-253

Ingredient substitution

- Solvent-extracted, dehulled soybean meal evaluations at Purdue University

- Hybrid striped bass – 40% of diet
- Yellow perch – 30% of diet
- Largemouth bass – 50% of diet

- Channel catfish – 50% of diet
- Trout/salmon - <17% of diet

*Ingredient substitution

- Tolerance of SBM in the 30-50% of diet for piscivorous species range is high.
- Are species evaluated more tolerant? Or, did formulation approach impact results?

* Factors that may contribute to limited use

  * Methods – replacement of fish meal with single test feedstuff

    * Reality – use blends of feedstuffs and fish meal-free, all plant diets have been developed for a variety of species

  * Nutritional deficiencies?

*Ingredient substitution

* Subsequent studies using maximum concentrations of soybean meal were designed to develop fish meal-free diets for hybrid striped bass and yellow perch.

* Combinations of animal by-product meals (poultry) with soybean meal supported similar weight gain to fish meal control diets in both species

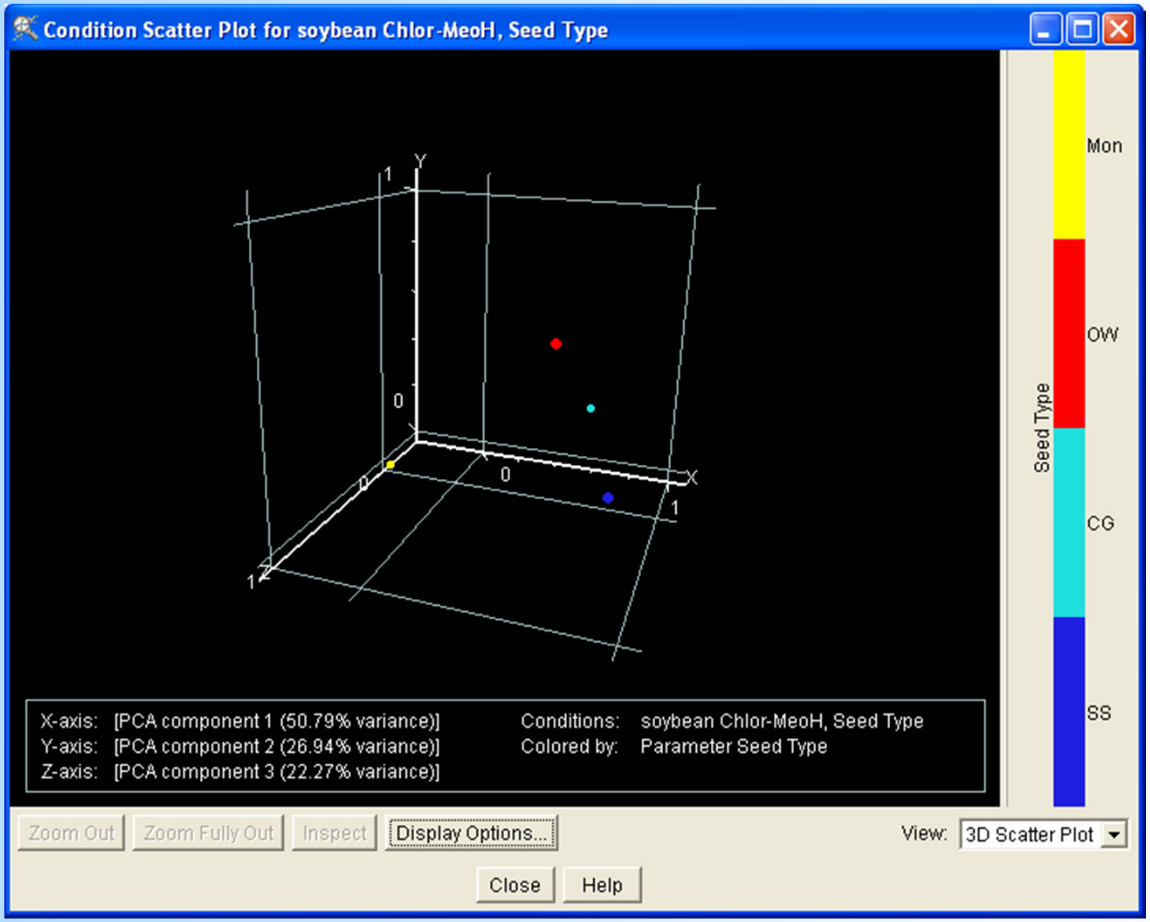
* Fish meal-free diets are possible!

*Potential new approaches

* Applied research – Blends of protein feedstuffs to meet essential amino acid and mineral requirements

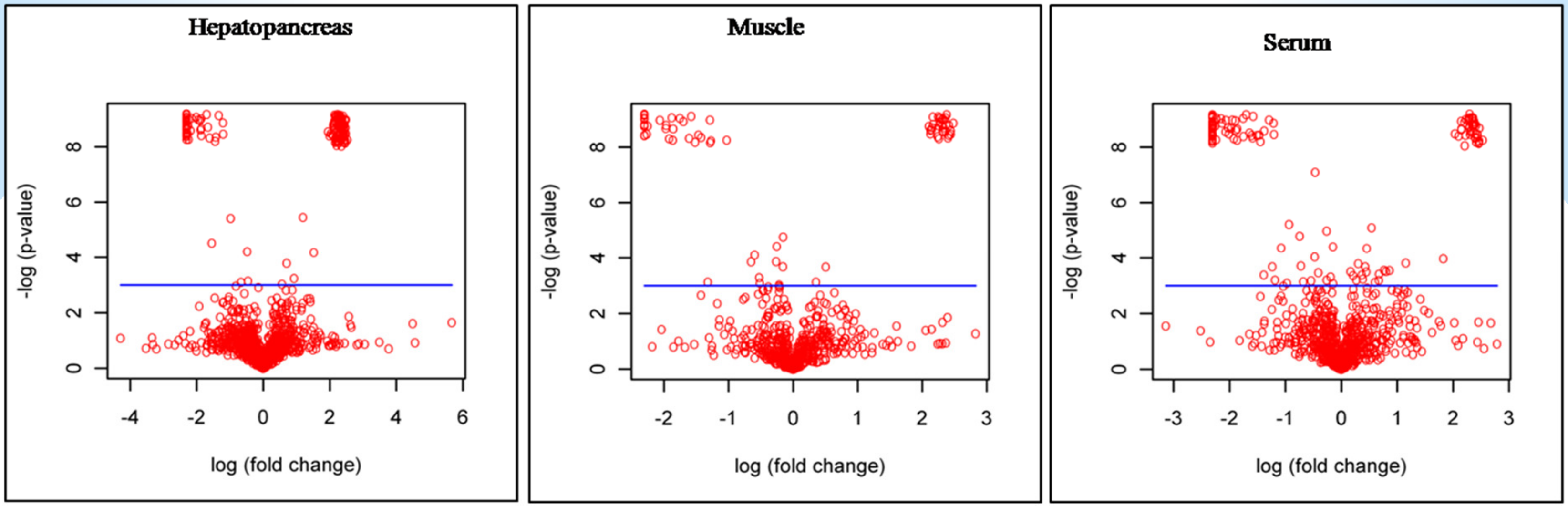
* Basic research – New enabling technologies
* Metabolomics – identification of all metabolites in samples
* Proteomics – identification of proteins

* Applied to whole organisms, targeted nutrients, protein ingredients and ingredients


Condition Scatter Plot for soybean Chlor-MeoH, Seed Type
Mon
OW
CG
SS
Seed Type
X-axis: [PCA component 1 (50.79% variance)]
Y-axis: [PCA component 2 (26.94% variance)]
Z-axis: [PCA component 3 (22.27% variance)]
Conditions: soybean Chlor-MeoH, Seed Type
Colored by: Parameter Seed Type
Zoom Out
Zoom Fully Out
Inspect
Display Options...
View:
3D Scatter Plot
Close
Help

Potential new approaches

* Metabolomics – marine shrimp, cholesterol study



Comparison	Total peaks detected	Significantly changed peaks[1]	Peaks identified	Compound present in KEGG[2]
SL vs. SCL				
Hepatopancreas	2309	135(5.85)	50	5
Muscle	1006	55(5.47)	17	3
Hemolymph	1120	95(8.48)	40	6

*Potential new approaches

* Metabolomics – shrimp/cholesterol

Hepatopancreas		Muscle		Serum	
Metabolite	Fold change	Metabolite	Fold change	Metabolite	Fold change
L-Serine	10.00	Glycerol	10.00	L-Tyrosine	0.12
L-Valine	10.00	L-Alanine	3.61	5-Oxoproline	0.11
Methylmalonic acid	0.14	L-Proline	0.10	L-Methionine	0.10
Malonic acid	0.11	Glycine	0.10	Cholesterol	0.10
L-Leucine	0.11			Malonic acid	0.09

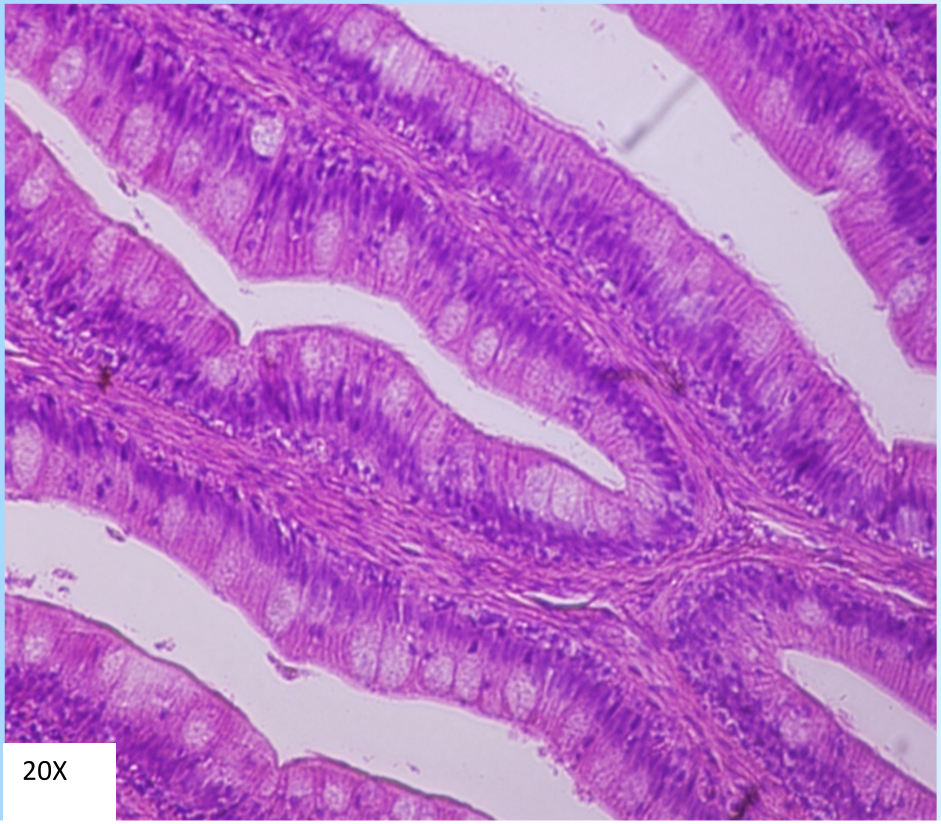
Effect of lack of dietary cholesterol supplementation on the expression of muscle protein in Pacific white shrimp

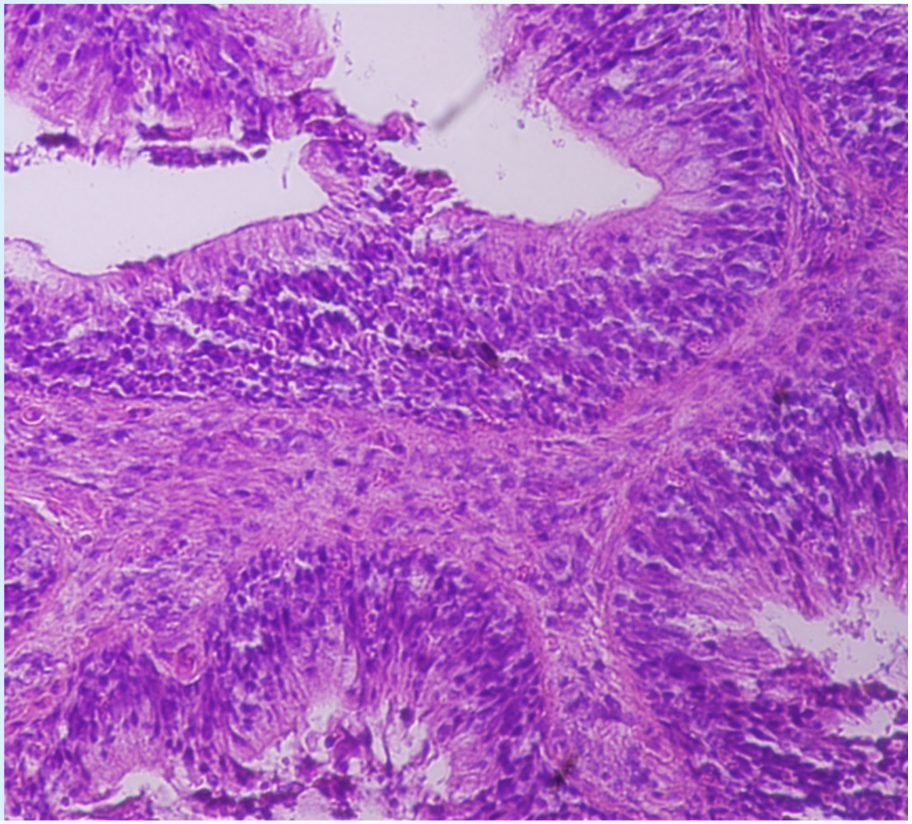
SSP number	Protein name	Fold change (SL/SCL)
2508	Pyruvate kinase	3.85
8205	Arginine kinase	0.21
3811	Hemocyanin	0.18
8207	Arginine kinase	0.17
8204	Arginine kinase	0.17
0404	SCP beta chain	0.04
8206	Arginine kinase	0.03
5605	Arginine kinase	0.01
7609	GAPDH	0.003
6608	Arginine kinase	0.002
7613	GAPDH	0.002
8402	GAPDH	0.001

Lack of cholesterol supplementation affected energy metabolism in the muscle

*Potential new approaches

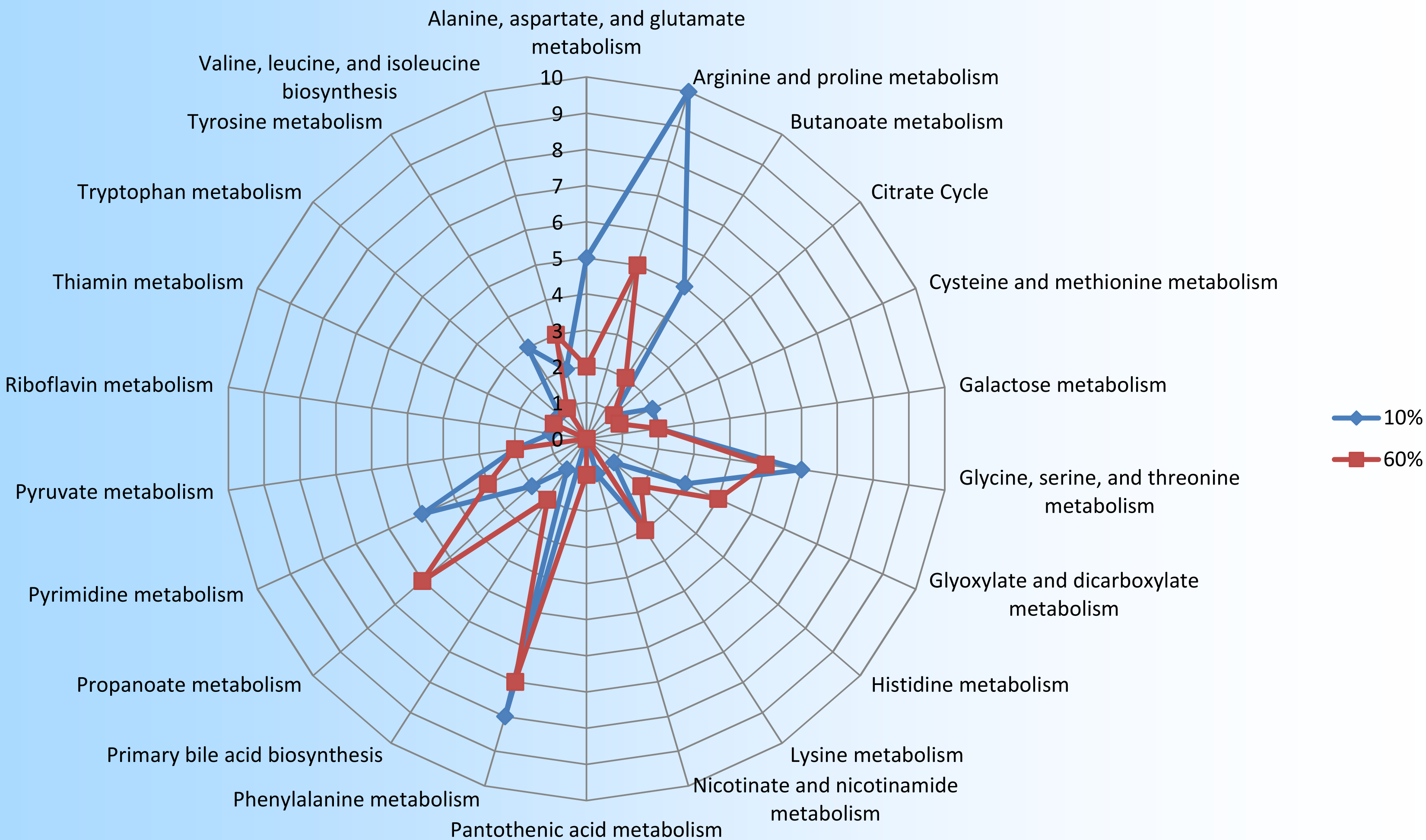
* Metabolomics – Largemouth bass - graded levels of dietary soybean meal substituted for an isonitrogenous amount of fish meal (10, 20, 30, 40, 50 or 60% of diet)





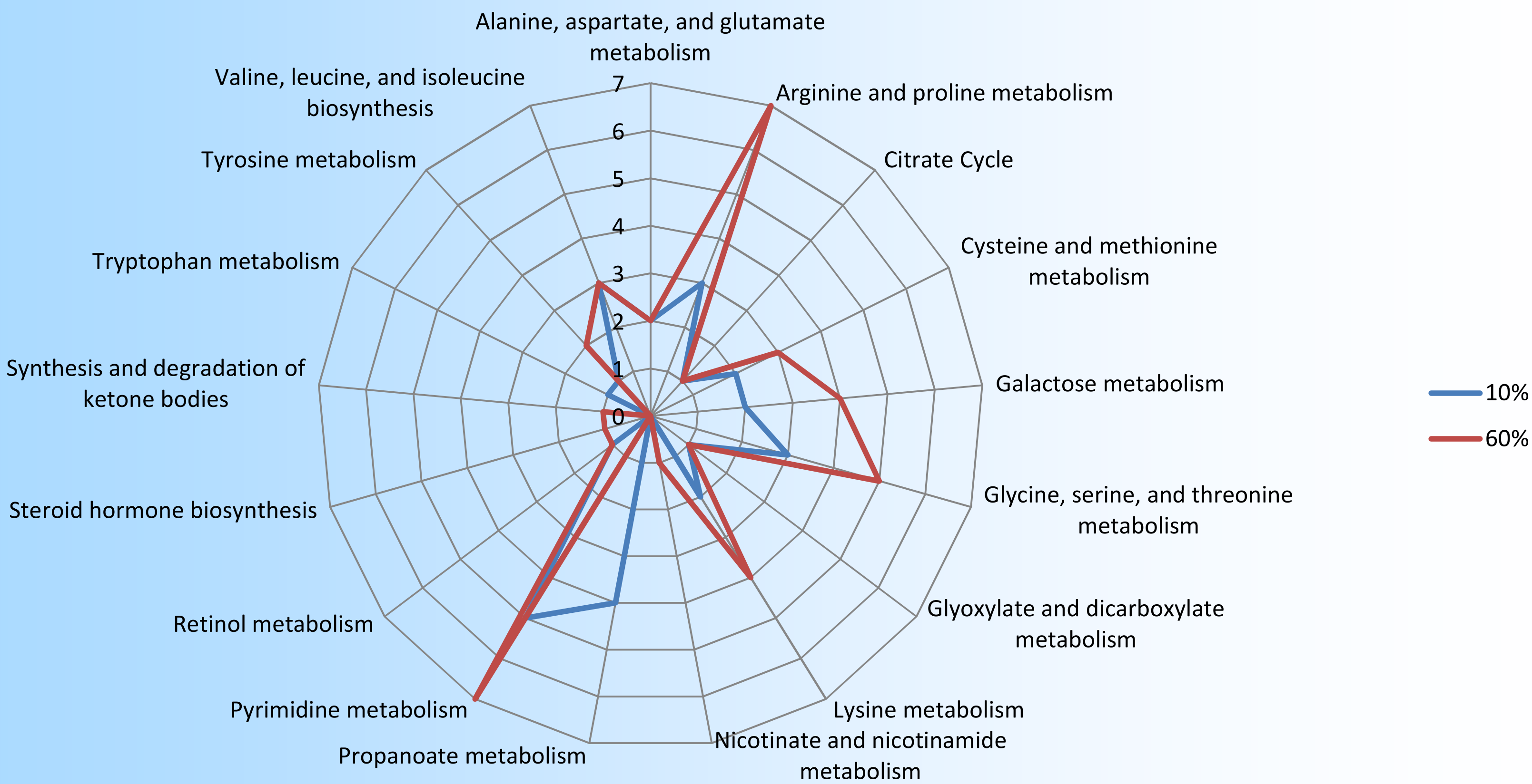
* Potential new approaches

* Metabolomics – Largemouth bass – soybean meal, 10 and 60%, GIT



* Potential new approaches

* Metabolomics – Largemouth bass – soybean meal, 10 and 60%, liver



*Potential new approaches summary

* -Omics offer a broader view of metabolic events
* May identify dietary alterations needed as we adopt use of new ingredients

*Conclusions

- Relatively few nutritional requirements quantified for culture species, but production has been established
- Volume of production is insufficient to justify manufacture of species specific diet, but data are available to formulate
- Trout diets in routine use, yet trout diets may not be optimum for growth, health and reproduction in emerging species
- New enabling technologies may facilitate understanding nutritional needs and interactions

*Sustainable?

Economic

Environmental

Sociological

* Thank you for your attention