One fish, two fish, feed fish, food fish

Meeting nutritional challenges in aquaculture and aquatic natural resources management

Jesse T. Trushenski
Aquaculture production has continually outstripped projections, and there is little reason to believe that it will not continue to do so. –World Bank 2006
304,000 MT of food fish were raised in the U.S. in 2007

$672 million in food fish sales
$18 million in sport fish sales
$38 million in bait fish sales

U.S. aquaculture is a billion dollar industry

NOAA 2009
Rainbow Trout
Hybrid Striped Bass
Bluegill

- 12,931 MT coldwater sportfish
- 294 MT coolwater sportfish
- 1,012 MT warmwater sportfish
- 5,424 MT salmon and steelhead
- 158 MT rare or declining forage
- 198 MT

~1.75 billion fish stocked by federal & state agencies in 2004

Halverson 2008
Nutritional Demands

Omnivores  Carnivores
Fish have high protein demands…

<table>
<thead>
<tr>
<th>Species</th>
<th>Dietary Protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asian Sea Bass</td>
<td>45</td>
</tr>
<tr>
<td>Atlantic Halibut</td>
<td>51</td>
</tr>
<tr>
<td>Atlantic salmon</td>
<td>55</td>
</tr>
<tr>
<td>Tilapias</td>
<td>30-40</td>
</tr>
<tr>
<td>Pacific salmonids</td>
<td>40-45</td>
</tr>
<tr>
<td>Carps</td>
<td>31-43</td>
</tr>
<tr>
<td>Eels</td>
<td>40-45</td>
</tr>
<tr>
<td>Sea Basses</td>
<td>45-50</td>
</tr>
<tr>
<td>Sea Breams</td>
<td>50-55</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Dietary Protein (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freshwater Basses</td>
<td>35-47</td>
</tr>
<tr>
<td>Trouts</td>
<td>40-53</td>
</tr>
<tr>
<td>Flatfishes</td>
<td>50-51</td>
</tr>
<tr>
<td>Catfish</td>
<td>32-36</td>
</tr>
<tr>
<td>Beef Cattle</td>
<td>7-18</td>
</tr>
<tr>
<td>Dairy Cattle</td>
<td>12-18</td>
</tr>
<tr>
<td>Sheep</td>
<td>9-15</td>
</tr>
<tr>
<td>Swine</td>
<td>12-13</td>
</tr>
<tr>
<td>Poultry</td>
<td>14-28</td>
</tr>
</tbody>
</table>

…but require amino acids, not protein

Halver and Hardy, 2002
### Essential amino acid requirements...

<table>
<thead>
<tr>
<th>Essential Amino Acids</th>
<th>Estimated Requirement (Rainbow Trout)</th>
<th>Fish Meal Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arginine</td>
<td>3.3-5.9</td>
<td>6.2</td>
</tr>
<tr>
<td>Histidine</td>
<td>1.6</td>
<td>2.8</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>2.4</td>
<td>4.2</td>
</tr>
<tr>
<td>Leucine</td>
<td>4.4</td>
<td>7.2</td>
</tr>
<tr>
<td>Lysine</td>
<td>3.7-6.1</td>
<td>7.8</td>
</tr>
<tr>
<td>Methionine</td>
<td>1.8-3.0</td>
<td>3.4</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>4.3-5.2</td>
<td>3.9</td>
</tr>
<tr>
<td>Threonine</td>
<td>3.2-3.7</td>
<td>4.2</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>0.5-1.4</td>
<td>0.8</td>
</tr>
<tr>
<td>Valine</td>
<td>3.1</td>
<td>5.0</td>
</tr>
</tbody>
</table>

All data expressed as % crude protein

*Halver and Hardy, 2002; Omega Protein, Inc., 2006*
**Fish have high lipid demands too…**

<table>
<thead>
<tr>
<th>Species</th>
<th>Dietary Lipid (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trout</td>
<td>18-20</td>
</tr>
<tr>
<td>Other Salmonids</td>
<td>20-30</td>
</tr>
<tr>
<td>Tilapia</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Sea Breams</td>
<td>10-15</td>
</tr>
<tr>
<td>Carp</td>
<td>&lt;18</td>
</tr>
<tr>
<td>Sea Basses</td>
<td>12-18</td>
</tr>
<tr>
<td>Yellow tail</td>
<td>11</td>
</tr>
<tr>
<td>Red drum</td>
<td>7-11</td>
</tr>
<tr>
<td>Grouper</td>
<td>13-14</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Dietary Lipid (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milk Fish</td>
<td>7-10</td>
</tr>
<tr>
<td>Catfish</td>
<td>5-6</td>
</tr>
<tr>
<td>Turbot</td>
<td>&lt;15</td>
</tr>
<tr>
<td>Sole</td>
<td>5</td>
</tr>
<tr>
<td>Beef Cattle</td>
<td>1-2</td>
</tr>
<tr>
<td>Dairy Cattle</td>
<td>1-2.5</td>
</tr>
<tr>
<td>Sheep</td>
<td>2.5-3</td>
</tr>
<tr>
<td>Swine</td>
<td>2-6</td>
</tr>
<tr>
<td>Poultry</td>
<td>~3</td>
</tr>
</tbody>
</table>

**…but require fatty acids, not lipid**

Guillaume et al. 2001
# Essential fatty acid requirements...

<table>
<thead>
<tr>
<th>Species</th>
<th>Advanced Juvenile/Adult Requirement</th>
<th>Fish Oil Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainbow Trout</td>
<td>18:3n-3 (0.7-1.0%) n-3 LC-PUFA (0.4-0.5%)</td>
<td>18:2n-6 (~1.7%)</td>
</tr>
<tr>
<td>Common Carp</td>
<td>18:2n-6 (1.0%) 18:3n-3 (0.5-1.0%)</td>
<td>18:3n-3 (~2.0%)</td>
</tr>
<tr>
<td>Tilapia</td>
<td>18:2n-6 (0.5-1.0%)</td>
<td></td>
</tr>
<tr>
<td>Various Pacific Salmonids</td>
<td>18:2n-6 (1.0%) 18:3n-3 (1.0%)</td>
<td>20:5n-3 (~13%)</td>
</tr>
<tr>
<td>Gilthead Seabream</td>
<td>n-3 LC-PUFA (0.9-1.9%)</td>
<td>22:6n-3 (~15%)</td>
</tr>
<tr>
<td>Red Seabream</td>
<td>22:6n-3 (0.5%) 20:5n-3 (1.0%)</td>
<td>LC-PUFA (~30%)</td>
</tr>
<tr>
<td>Striped Jack</td>
<td>22:6n-3 (1.7%)</td>
<td></td>
</tr>
</tbody>
</table>

*All values reported as % of dry diet*

Halver and Hardy 2002
Amino & Fatty Acids

Metamorphosis

Reproduction

Behavior

Stress Response

Biosynthetic Rates

Cell Signaling

Appetite Regulation

Growth and Development

Osmoregulation

Pigmentation

Membrane Competence

Metabolic Regulation

Endocrine Status

Seafood Quality

Antioxidative Defense

Immunity and Survival

Energy Substrates

Immunity and Survival

Energy Substrates

Growth and Development

Osmoregulation

Tocher 2003, Li et al. 2008
What will limit the growth of aquaculture?

“...much research has focused on finding replacements for fish meal... Partial replacements have been achieved. However, no dramatic breakthroughs have been reported, and the share of fish meal and fish oil used in aquaculture is increasing...” (FAO 2008)
What will limit the growth of aquaculture?

“[G]iven the difficulty in replacing fish oils...it is clear that competition for fish oil is likely to be a more serious obstacle for some sections of the aquaculture industry.” (FAO 2008)
Lower feed costs
EAA, EFA, etc. may be low or absent
Palatable, nutrient dense, highly digestible
Maintain integrity of product
Readily available, sustainable
Decreased cost of production
Safer products?
Replacing fish meal...production effects
Case study with soy protein concentrate in HSB feeds

Fish meal sparing can reduce the palatability of feeds, especially for carnivorous fish

Blaufuss and Trushenski, in preparation
Replacing fish meal…production effects
Case study with soybean meal in HSB feeds

Even when intake is good, EAA deficiencies and utilization problems can still develop with reduced fish meal feeds

Laporte and Trushenski, in preparation
Replacing fish meal...stress effects
Case study with soybean meal in HSB feeds

Fish meal sparing may lead to unintended consequences in terms of livestock resilience

Laporte and Trushenski, in preparation
Replacing fish oil…production effects
Case study with various oils in HSB feeds

Fish oil sparing doesn’t typically impact production performance

Trushenski et al. 2008
Replacing fish oil…production effects
Case study with canola oil in HSB feeds

EFA deficiencies associated with fish oil replacement can lead to impaired production

Lewis and Kohler 2008
Replacing fish oil...fillet effects
Case study with soy oil in cobia feeds

Fish oil sparing affects fillet composition and associated nutritional value

Trushenski et al., in press

Line of Equality
- 67% FO
- 33% FO
- 0% FO
Replacing fish oil...reproductive effects
Case study with corn oil in white bass broodstock feeds

\[ y = -6.13x + 65.35 \]
\[ R^2 = 0.90 \]
\[ P < 0.05 \]

Lane and Kohler, 2006
The challenges...

Fish meal and oil are finite resources which aquaculture increasingly monopolizes.

Sources of amino acids abound, but may be improperly balanced, unpalatable.

*Alternative proteins impact production performance, possibly livestock resilience.*

Sources of essential fatty acids can be limiting.

*Alternative lipids affect fillet nutritional value, reproductive performance.*
The challenges...

Nutritional research and understanding of requirements in fishes is meager relative to other livestock.
The challenges...

Aquaculture Projects = <2% of ~1000

Total R & D funding (2007) = $654 million
Total Aquaculture R & D: $17.6 million

Aquaculture = 2.7% of research investments

Gary Jensen, National Program Leader for Aquaculture, USDA NIFA, pers. comm. March 2010
The opportunities…

Novel feedstuffs with greater performance in aquafeeds
  Tailoring of ‘traditional’ feedstuffs for aquatic livestock, investigation of new resources

Palatants, attractants, and ‘nutriceuticals’
  Reduced feed intake can be corrected, resilience improved through dietary modification

Finishing feeds, novel fatty acid sources to tailor fillets
  Have your n-3 long-chain PUFA and eat it too
The opportunities...

Seafood demand continues to rise

*Roughly half of seafood consumed is farm-raised*

Food security for 9 billion people by 2050

*Seafood provides 1/3 of the population with 15% or more of daily protein*

Aquaculture produces protein efficiently

- Swine: 3 to 1
- Beef Cattle: 8 to 1
- Poultry: 2 to 1
- Fish: 1-2 to 1
The way forward…

Greater and consistent funding of nutrition research in aquaculture

*Basic research to understand requirements, interactions, etc. for long-term solutions*

*Applied research to demonstrate effectiveness, provide practical short-term solutions*

Linkage with other industries

*Utilize existing agribusiness infrastructure, knowledge*
Acknowledgments

Fisheries and Illinois Aquaculture Center
Archer Daniels Midland Company
Illinois Soybean Association
North Central Regional Aquaculture Center
National Science Foundation
USDA National Research Initiative Cooperative Research, Education, and Extension Service
References


Guillaume et al. 2001 : Nutrition and feeding of fish and crustaceans. Springer-Praxis, Chichester, UK.


References


Trushenski et al. in press: Effect of replacing dietary fish oil with soybean oil on production performance and fillet lipid and fatty acid composition of juvenile cobia Rachycentron canadum. Aquaculture Nutrition, in press.

World Bank 2006: Aquaculture review: Changing the face of the waters, meeting the promise and challenge of sustainable aquaculture. Report 36622-GLB. IBRD/World Bank, Washington, DC