Latest Facts for Fish Feed Formulations
(NRC bulletin on Nutrient Requirements for Fish and Shrimp)

By

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The US Dept of Agriculture, NOAA of the Dept of Commerce, the US Soybean Board, and the National Research Council decided he 1993 bulletin on Nutrient Requirements of Fish was seriously outdated.
The team

- Ronald W. Hardy, Chair, University of Idaho, USA
- Dominique Bureau, University of Guelph, Canada
- Louis D’ Abramo, Mississippi State University, USA
- Allen Davis, Auburn University, USA
- Delbert Gatlin, Texas A & M University, USA
- John E. Halver, University of Washington, USA
- Ashlid Krogdahl, Norwegian School Veterinary Science, Norway
- Austin Lewis, NAS/NRC, Washington DC, USA
- Francoise Medale, INRA, France
- Shi-Yen Shiau, Taiwan Ocean University, Taiwan
- Douglas Tocher, University of Stirling, Scotland

The National Academy of Sciences assembled an international team, led by Ron Hardy, with members from Canada, Norway, Scotland, France, China, & the USA.
The Nutrient Requirements of Fish & Shrimp Team

Here they are, at Woods Hole, MA, assembled for the task of revising and updating the old bulletin.
The Topics

- Digestive physiology
- Dietary energy
- Protein and Amino Acids
- Lipids
- Carbohydrates and Fiber
- Minerals
- Vitamins
- Feed Additives
- Digestibility and availability
- Nutrient delivery
- Ingredients and processing
- Replacing marine resources
- Research Needs

The topics covered were more varied and extensive than in the old bulletin, and included the latest published findings from around the world.
Updated requirements

- Amino Acids
- Energy and Fiber
- Lipids
- Minerals
- Vitamins

Probably the most important aspect of the bulletin was the update on nutrient requirements of different classes of fish and shrimp.
Nutrient Requirement Tables

- Requirements of freshwater fish
- Requirements of marine fish
- Requirements of shrimp
- Deficiency signs of essential nutrients
- Feedstuffs ingredient tables

The nutrient requirement tables were subdivided into freshwater fish, marine fish, and shrimp. Two additional tables were added - one on deficiency signs and one on feedstuffs ingredients.
All publications on freshwater fish species requirements could not be included, and therefore the freshwater fish requirements were focused on the 5 major species that are the largest contributors to aquaculture production: channel catfish, rainbow trout, pacific salmon, common carp, and tilapia.
I have summarized the freshwater fish Amino Acid requirements in double columns, one showing the 1993 recommendations and the other column showing the latest changes in red that the committee agreed upon for a conservative value for feed formulations.
Cyprinid production is the leader in world aquaculture, especially in China and SE Asia.
# Freshwater Fish Requirements, Minerals

<table>
<thead>
<tr>
<th></th>
<th>Channel Catfish</th>
<th>Rainbow trout</th>
<th>Pacific salmon</th>
<th>Common Carp</th>
<th>Tilapia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Macro minerals (% diet)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium</td>
<td>R</td>
<td>0.45h</td>
<td>1E</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Chlorine</td>
<td>R</td>
<td>0.17</td>
<td>0.9E</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.04</td>
<td>0.04</td>
<td>0.05</td>
<td>0.05</td>
<td>NT</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.45</td>
<td>0.33</td>
<td>0.60</td>
<td>0.70</td>
<td>0.60</td>
</tr>
<tr>
<td>Potassium</td>
<td>R</td>
<td>0.26</td>
<td>0.70</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Sodium</td>
<td>R</td>
<td>0.06</td>
<td>0.6E</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td><strong>Micro minerals (mg/kg diet)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>NT</td>
</tr>
<tr>
<td>Iodine</td>
<td>1.10E</td>
<td>1.10</td>
<td>1.10</td>
<td>1.10</td>
<td>0.6-1.1</td>
</tr>
<tr>
<td>Iron</td>
<td>30</td>
<td>30</td>
<td>60</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Manganese</td>
<td>2.4</td>
<td>2.40</td>
<td>1.3</td>
<td>12</td>
<td>R</td>
</tr>
<tr>
<td>Selenium</td>
<td>0.25</td>
<td>0.25</td>
<td>0.3</td>
<td>0.15</td>
<td>R</td>
</tr>
</tbody>
</table>
Channel catfish is one of the experimental animals used for aquaculture production and research.
## Freshwater Fish Requirements, WS Vitamins

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Channel Catfish</th>
<th>Rainbow trout</th>
<th>Pacific salmon</th>
<th>Common Carp</th>
<th>Tilapia</th>
</tr>
</thead>
<tbody>
<tr>
<td>mg/kg dry diet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thiamin</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>R</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>9</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>Pyridoxine (B6)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Pantothenic acid</td>
<td>15</td>
<td>15</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Niacin</td>
<td>14</td>
<td>14</td>
<td>10</td>
<td>10</td>
<td>R</td>
</tr>
<tr>
<td>Biotin</td>
<td>R</td>
<td>R</td>
<td>0.15</td>
<td>0.15</td>
<td>R</td>
</tr>
<tr>
<td>Cyanocobalaminine (B12)</td>
<td>R</td>
<td>R</td>
<td>0.01E</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Folate</td>
<td>1.50</td>
<td>1.50</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Choline</td>
<td>400</td>
<td>400</td>
<td>1000</td>
<td>800</td>
<td>800</td>
</tr>
<tr>
<td>Myoinositol</td>
<td>NR</td>
<td>NR</td>
<td>300</td>
<td>300</td>
<td>300</td>
</tr>
<tr>
<td>Ascorbic Acid (C)</td>
<td>25-50</td>
<td>15</td>
<td>50</td>
<td>20</td>
<td>50</td>
</tr>
</tbody>
</table>

The water-soluble vitamin requirements listing has been expanded, especially for carp and tilapia.
Water soluble vitamins

The apparent requirement can be calculated from maximum growth, maximum enzyme activity, or at maximum tissue stores.
Tilapia were included in the chart for fat soluble vitamin recommendations.
### Freshwater Fish Req. FS Vitamins

<table>
<thead>
<tr>
<th>VITAMINS</th>
<th>Channel</th>
<th>Catfish</th>
<th>Rainbow trout</th>
<th>Pacific salmon</th>
<th>Common Carp</th>
<th>Tilapia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fat Soluble</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A (IU/kg)</td>
<td>1000-2000</td>
<td>0.6 mg/kg</td>
<td>2500</td>
<td>0.75mg/kg</td>
<td>2500</td>
<td>R</td>
</tr>
<tr>
<td>D (IU/kg)</td>
<td>500</td>
<td>12.5µg</td>
<td>2400</td>
<td>40µg</td>
<td>NT</td>
<td>NR</td>
</tr>
<tr>
<td>E (mg/kg)</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>K (mg/kg)</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
</tbody>
</table>

The holes in the chart are a scatter diagram of areas for future research.
Coho salmon

The marine fish requirements were expanded to include yellowtail, red drum, sea bass, flounder, grouper, and cobia.
<table>
<thead>
<tr>
<th>Marine Fish (%)</th>
<th>Rainbow Trout</th>
<th>Yellowtail</th>
<th>Red Drum</th>
<th>European Sea Bass</th>
<th>Japanese Flounder</th>
<th>Grouper</th>
<th>Asian Sea Bass</th>
<th>Cobia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arginine</td>
<td>1.6</td>
<td>1.8</td>
<td>1.8</td>
<td>2.0</td>
<td>1.8</td>
<td></td>
<td></td>
<td>1.8</td>
</tr>
<tr>
<td>Lysine</td>
<td>2.40</td>
<td>1.9</td>
<td>1.7</td>
<td>2.2</td>
<td>2.6</td>
<td>2.8</td>
<td>2.1</td>
<td>2.3</td>
</tr>
<tr>
<td>Methionine</td>
<td>0.70</td>
<td>0.8</td>
<td>0.8</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td>Methionine+ cystine</td>
<td>1.10</td>
<td>1.2</td>
<td>1.2</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td>1.2</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>1.10</td>
<td>1.2</td>
<td>1.2</td>
<td>1.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phenylalanine + Tyrosine</td>
<td>1.10</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Threonine</td>
<td>1.10</td>
<td>0.8</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tryptophan</td>
<td>0.30</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valine</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taurine</td>
<td>R</td>
<td>R</td>
<td>0.2</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
</tbody>
</table>

The chart shows many voids, but does include levels for most of the critical limiting amino acids. The values shown are recommendations for normal growth under normal conditions.
Cobia is one new rapidly growing species for many areas of marine fish production.
The marine fish requirements for minerals have only a few sparse quantitative recommendations. While sodium is required for life, marine fish have ample opportunities to obtain this element from the environment.
Halibut

Flatfish were also included in this list.
## Marine Fish Requirements, **ws Vitamins**

<table>
<thead>
<tr>
<th>Marine Fish</th>
<th>Rainbow Trout</th>
<th>Yellowtail</th>
<th>Red Drum</th>
<th>European Sea Bass</th>
<th>Japanese Flounder</th>
<th>Grouper</th>
<th>Asian Sea Bass</th>
<th>Cobia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>mg/kg</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thiamin</td>
<td>1</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riboflavin</td>
<td>4</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyridoxine (B6)</td>
<td>3</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pantothenic acid</td>
<td>20</td>
<td>36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Niacin</td>
<td>10</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biotin</td>
<td>0.15</td>
<td>0.67</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyanocobalmine (B12)</td>
<td>R</td>
<td>0.05</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Folate</td>
<td>1</td>
<td>1.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Choline</td>
<td>800</td>
<td>1000</td>
<td>600</td>
<td></td>
<td></td>
<td></td>
<td>700</td>
<td></td>
</tr>
<tr>
<td>Myoinositol</td>
<td>300</td>
<td>420</td>
<td></td>
<td></td>
<td></td>
<td>350</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ascorbic acid (C)</td>
<td>20</td>
<td>43-52</td>
<td>15</td>
<td>20</td>
<td>18</td>
<td>30</td>
<td>45-54</td>
<td></td>
</tr>
</tbody>
</table>

Water soluble vitamin requirements were only available for the rainbow trout and the yellowtail. Again, vast areas for new research needs are apparent.
Considerable research has been conducted with European Sea Bass.
Fat-soluble vitamin requirements have been listed for most of these species, and general lipid requirements for the polyunsaturated fatty acids have been studied during the past 10 years.
## Water-soluble Vitamin Deficiency Signs

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Signs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thiamin</td>
<td>Poor appetite, muscle atrophy, convulsions, instability and loss of equilibrium, edema, poor growth, hyperexcitability to sudden stimulus, with paralysis or aberrant swimming</td>
</tr>
<tr>
<td>Riboflavin</td>
<td>Corneal vascularization, cloudy lens, hemmorhagic eyes, photophobia, dim vision, incoordination, abnormal pigmentation of iris, striated constrictions of abdominal wall, dark coloration, poor appetite, anemia, poor growth, cataracts (bilateral)</td>
</tr>
<tr>
<td>Pyridoxine (B6)</td>
<td>Nervous disorders, epileptiform fits, hyper-irritability, ataxia, anemia, loss of appetite, edema of peritoneal cavity, colorless serous fluid, convulsions, paralysis (tail down, head up position) rapid and gasping breathing, flexing of opercles, rapid post mortem rigor mortis,</td>
</tr>
</tbody>
</table>
Water-soluble vitamin deficiency signs (cont)

Pantothenic acid  Clubbed gills, prostration, loss of appetite, necrosis and scarring, cellular atrophy, gill exudate, sluggishness, poor growth, fusion of gill lamella

Inositol  Poor growth, increased gastric emptying time, skin lesions, distended abdomen, hemorrhages at base of fins

Biotin  Loss of appetite, lesions in colon, skin coloration, muscle atrophy, spastic convulsions, fragmentation of erythrocytes, poor growth, skin lesions

Folic acid  Poor growth, lethargy, fragility of caudal fin, dark coloration, macrocytic anemia, absence of immature erythrocytes

Choline  Poor growth, poor food conversion, hemorrhagic kidney and intestine, light yellow livers, bulging eyes, anemia, bulging abdomen
Water-soluble deficiency signs (cont)

Nicotinic acid  Loss of appetite, lesions in colon, jerky or difficult motion, weakness, poor growth, edema of stomach and colon, muscle spasm while resting.

Cyanocobalamine (B12) Poor appetite, low hemoglobin, macrocytic anemia, fragmentation of erythrocytes, increased level of immature erythrocytes.

Ascorbic Acid (C) Scoliosis, lordosis, impaired collagen formation, altered cartilage, slow wound repair, eye lesions, hemorrhagic skin, liver, kidney intestine, and muscle.
No vitamin C

Scurvy is apparent in ascorbic acid deficient diets in most fish studied.
Fat-soluble vitamin deficiency signs

A  Impaired growth, eye lens displacement, depigmentation, corneal thinning and expansion, degeneration of retina, hemorrhages at base of fins, exophthalmia, edema, asites

D  Poor growth, tetany of white skeletal muscle, impaired calcium homeostasis, lethargy

E  (tocopherol) Reduced survival, poor growth, anemia, immature erythrocytes, variable-sized erythrocytes, erythrocyte fragility and fragmentation, nutritional muscular dystrophy, elevated body water, dermal depigmentation, acites, steatitis

K  Prolonged blood clotting, anemia, lipid peroxidation, reduced hematocrit, hemorrhages in muscle and viscera
<table>
<thead>
<tr>
<th>AA and Lipid deficiency signs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Histidine</td>
<td>lens cataracts</td>
</tr>
<tr>
<td>Methionine</td>
<td>lens cataracts</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>scoliosis, lordosis, cataracts</td>
</tr>
<tr>
<td>EPA &amp; DHA</td>
<td>(essential fatty acids) myocarditis, pale/swollen</td>
</tr>
<tr>
<td></td>
<td>(fatty) liver, intestinal steatosis, fin erosion,</td>
</tr>
<tr>
<td></td>
<td>bleeding from gills, lordosis, reduced reproductive</td>
</tr>
<tr>
<td></td>
<td>potential, shock syndrome</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>none known for fish, shrimp require cholesterol</td>
</tr>
<tr>
<td>Phospholipids</td>
<td>skeletal malformations</td>
</tr>
</tbody>
</table>
Mineral deficiency signs

**Magnesium**  Anorexia, poor growth, lethargy, calcinosis of kidney, spinal deformity, degeneration of muscle & epithelial cells, convulsions, cataracts, low Mg levels in tissues (bone), renal calcinosis

**Phosphorus**  Poor growth, poor feed efficiency, bone mineralization, cessation of feeding, low P levels in skin and bones, operculum and jaw deformities

**Copper**  Poor growth, cataracts, low tissue Cu levels
Mineral deficiency signs, cont.

Iodine  Thyroid hyperplasia (goiter)
Iron  Microcytic anemia, suppressed hematocrit, light colored liver,
   Hyperchromic normocytic anemia
Manganese  Poor hatchability, reduced growth, skeletal abnormalities,
   Short body dwarfism
Selenium  Poor growth, muscular dystrophy (if E is also low), High fry mortality, reduced glutathione peroxidase activity
Zinc  Poor growth, lens cataracts, fin erosion, short-body dwarfism, low tissue Zn levels, mortality
The committee agreed on priorities for these critical research needs

1. PROTEIN SOURCES:  
   a. Distillers byproduct meals  
   b. Microbial protein meal  
   c. Fish byproducts  
      d. SBTI negative soy bean meal  
   e. Grain processing meals  
   f. Algal preps

2. LIPID SOURCES:  
   a. Krill  
   b. Microbial  
      c. Fish byproducts  
      d. Squid  
   e. Corn and soy  
   f. Rapeseed

3. Larval diets & Feed technology  
   a. EFA levels and timing  
   b. Acceptance & utilization  
   c. Transition state  
   d. Predigested hydrolytic
CRITICAL RESEARCH NEEDS (2)

4. **Nutrigenomics**
   - Genetic engineering
   - Nutrient balance and expression
     - Gene expression for enzymes
     - Simple analytic arrays

5. **The Vitamins**
   - Reliable assay techniques
   - FS load & effect levels
     - WS efficiency levels

6. **Anti-nutrients**
   - Enzyme inhibitors
   - Cross reactions
     - Fiber types
     - Mycotoxins

Genetic engineering and gene expression for enzymes are a rapidly new area for research.
General outline of the DNA-microarray protocol

control  treated  

**gill/liver preparation**

**RNA extraction**

**labeled cDNA synthesis**

**hybridization**

**dataprocessing**

**data analysis**
Many more areas of research were expressed in the discussions for different classes of nutrients and species mentioned in the texts. A general summary of major areas of critical new research needs was compiled in the final chapter.
SPONSORS
Agriculture Research Service, USDA
NOAA, USDC
United States Soybean Board
National Research Council

This bulletin was only made possible by the sponsorship from the Agricultural Research Services, NOAA, United States Soybean Board, and the National Research Council endowment funds.
A massive list of specific references, summarizing current knowledge of the nutrient requirements of fish and of shrimp, was used to provide the specific data which the committee used to make the conservative recommendations that are listed in the bulletin.
We have come a long way in the last 10 years. Now it is up to you to fill in the voids for the nutrient requirements of the fish and shrimp we raise. Have fun. Thanks for your time.