

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Board, and the National Research Council decided the 1993 bulletin on Nutrient Requirements of Fish was seriously outdated.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.

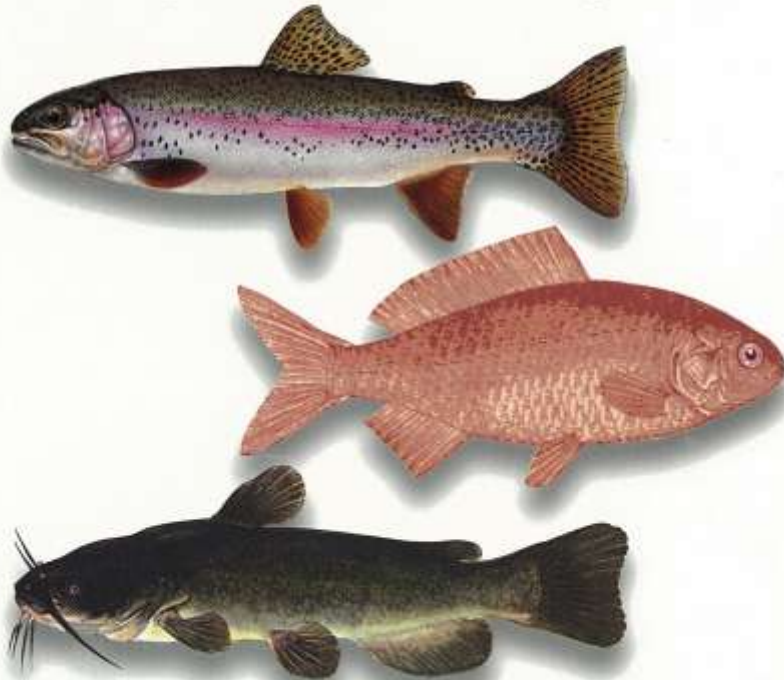
Nutrient Requirement Tables

- 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.

THIRD EDITION

FISH NUTRITION



Edited by

JOHN E. HALVER • RONALD W. HARDY

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.

Freshwater Fish Requirements, AA

	Channel Catfish		Rainbow trout		Pacific salmon		Common Carp		Tilapia	
% protein	old (1993)	New (2011)	old (1993)	New (2011)	old (1993)	New (2011)	old (1993)	New (2011)	old (1993)	New (2011)
AMINO ACIDS										
Arginine	1.20	1.20	1.50	1.50	2.04	2.20	1.31	1.70	1.18	1.20
Histidine	0.42	0.60	0.70	0.80	0.61	0.70	0.64	0.50	0.48	1.00
Isoleucine	0.73	0.80	0.90	1.10	0.75	1.00	0.76	1.00	0.87	1.00
Leucine	0.98	1.30	1.40	1.50	1.33	1.60	1.00	1.40	0.95	1.90
Lysine	1.43	1.60	1.80	2.40	1.70	2.20	1.74	2.20	1.43	1.60
Methionine		0.60		0.70		0.70		0.70		0.70
Methionine, cystine	0.64	0.90	1.00	1.10	1.36	1.10	0.94	1.00	0.90	1.00
Phenylalalanine		0.07		0.90		0.90		1.30		1.10
Phenylalalanine, tyrosine	1.40	1.60	1.80	1.80	1.73	1.80	1.98	2.00	1.55	1.60
Threonine	0.56	0.70	0.80	1.10	0.75	1.10	1.19	1.50	1.05	1.10
Tryptophan	0.14	0.20	0.20	0.30	0.17	0.30	0.24	0.30	0.28	0.30
Valine	0.84	0.80	1.20	1.20	1.09	1.20	1.10	1.40	0.78	1.50

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.

Common carp



Cyprinid production is the leader in world aquaculture, especially in China and SE Asia.

Freshwater Fish Requirements, Minerals

	Channel Catfish		Rainbow trout		Pacific salmon		Common Carp		Tilapia	
	old (1993)	New (2011)	old (1993)	New (2011)	old (1993)	New (2011)	old (1993)	New (2011)	old (1993)	New (2011)
Macro minerals (% diet)										
Calcium	R	0.45h	1E	? ?	NT	R	NT	0.03	R	0.70
Chlorine	R	0.17	0.9E	? ?	NT	NT	NT	NR	NT	0.15
Magnesium	0.04	0.04	0.05	0.05	NT	NT	0.05	0.05	0.06	0.06
Phosphorus	0.45	0.33	0.60	0.70	0.60	0.60	0.60	0.70	0.50	0.40
Potassium	R	0.26	0.70	? ?	0.80	0.80	NT	NT	NT	0.2-.03
Sodium	R	0.06	0.6E	? ?	NT	NT	NT	NT	NT	0.15
Micro minerals (mg/kg diet)										
Copper	5	5	3	3	NT	NT	3	3	R	5
Iodine	1.10E	1.10	1.10	1.10	0.6-1.1	1	NT	NT	NT	NT
Iron	30	30	60	? ?	NT	NT	150	150	NT	85
Manganese	2.4	2.40	1.3	12	R	NT	13	12	R	7
Selenium	0.25	0.25	0.3	0.15	R	R	NT	NT	NT	NT

Channel catfish



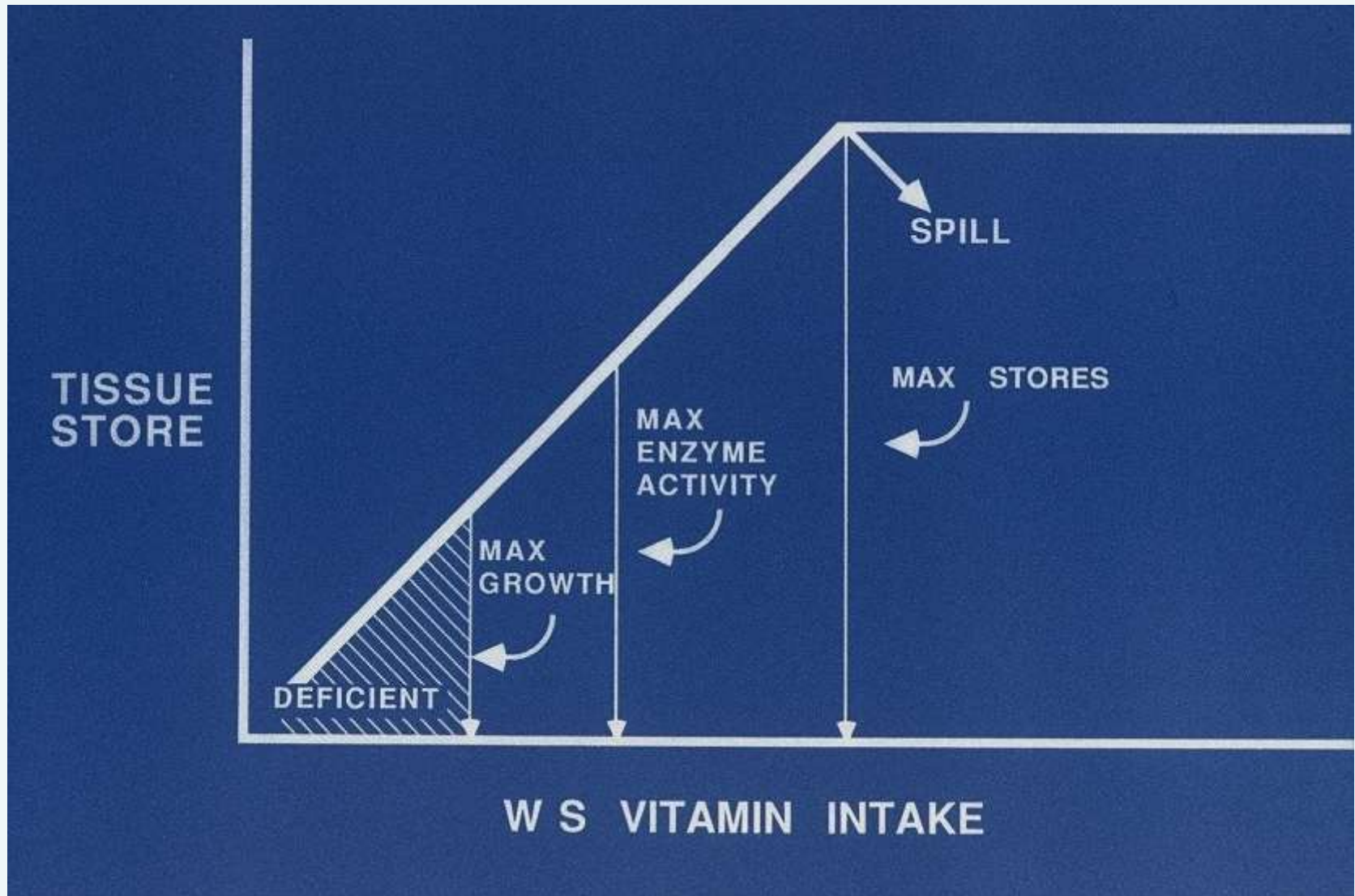
Channel catfish is one of the experimental animals used for aquaculture production and research.

Freshwater Fish Requirements, WS Vitamins

	Channel Catfish		Rainbow trout		Pacific salmon		Common Carp		Tilapia	
	old (1993)	New (2011)	old (1993)	New (2011)	old (1993)	New (2011)	old (1993)	New (2011)	old (1993)	New (2011)
<i>mg/kg dry diet</i>										
Thiamin	1	1	1	1	R	10	0.50	0.50	NT	NT
Riboflavin	9	9	4	4	7	7	7	7	6	6
Pyridoxine (B6)	3	3	3	3	6	6	6	6	NT	15
Pantothenic acid	15	15	20	20	20	20	30	30	10	10
Niacin	14	14	10	10	R	150	28	28	NT	26
Biotin	R	R	0.15	0.15	R	1	1	1	NT	0.06
Cyanocobalamin (B12)	R	R	0.01E	R	R	0.02	NR	NR	NR	NR
Folate	1.50	1.50	1	1	2	2	NR	NR	NT	1
Choline	400	400	1000	800	800	800	500	1500	NT	1000
Myoinositol	NR	NR	300	300	300	? ?	440	440	NT	400
Ascorbic Acid (C)	25-50	15	50	20	50	? ?	R	45	50	20

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



Tilapia were included in the chart for fat soluble vitamin recommendations.

Freshwater Fish Req. FS Vitamins

	Channel Catfish	Rainbow trout	Pacific salmon	Common Carp	Tilapia					
VITAMINS	old (1993)	New (2011)	old (1993)	New (2011)	old (1993)	New (2011)				
<i>Fat Soluble</i>										
A (IU/kg)	1000-2000	0.6 mg/kg	2500	0.75mg/kg	2500	R	4000	1.2 mg/kg	NT	1.8 mg/kg
D (IU/kg)	500	12.5µg	2400	40µg	NT	NR	NT	NT	NT	9µg
E (mg/kg)	50	50	50	50	50	50	100	100	50	60
K (mg/kg)	R	R	R	R	R	R	NT	NT	NT	NT

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.

Marine Fish Requirements, AA

Marine Fish (% protein)	Rainbow Trout	Yellowtail	Red Drum	European Sea Bass	Japanese Flounder	Grouper	Asian Sea Bass	Cobia
Argenine		1.6	1.8	1.8	2.0		1.8	
Histidine								
Isoleucine								
Leucine								
Lysine	2.40	1.9	1.7	2.2	2.6	2.8	2.1	2.3
Methionine	0.70	0.8	0.8		0.9		0.8	0.8
Methionine+cystine	1.10	1.2	1.2	1.0			1.2	1.1
Phenylalanine								
Phenylalanine + Tyrosine								
Threonine	1.10		0.8	1.2				
Tryptophan	0.30			0.3				
Valine								
Taurine		R	R	0.2	R	R	R	R

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



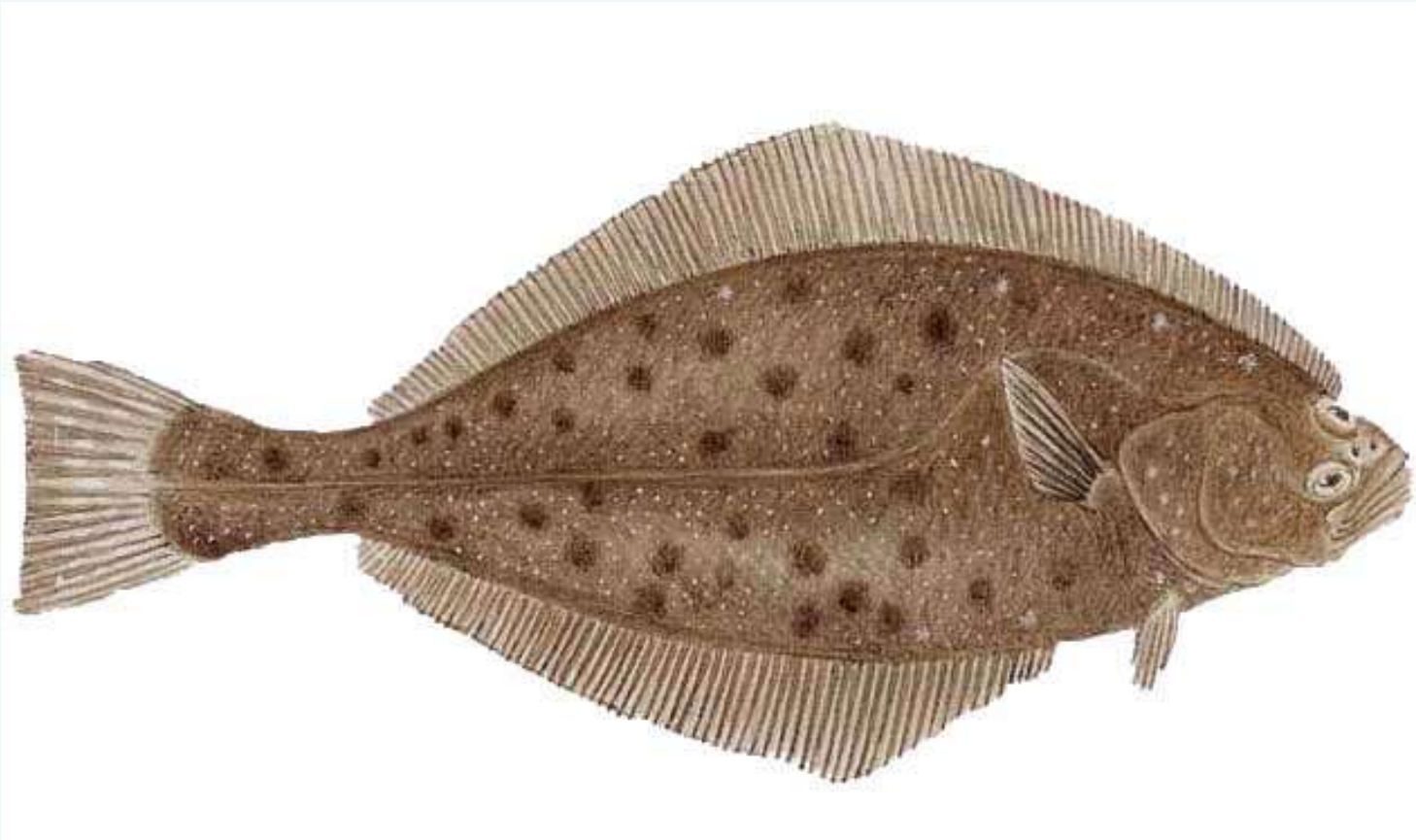
Cobia is one new rapidly growing species for many areas of marine fish production.

Marine Fish Requirements, Minerals

Marine Fish (% protein)	Rainbow Trout	Yellowtail	Red Drum	European Sea Bass	Japanese Flounder	Grouper	Asian Sea Bass	Cobia
<i>Macro minerals (% diet)</i>								
Chlorine	NT		R					
Phosphorus	0.70		0.8	0.7	0.6			
Sodium	NR		R					
<i>Micro minerals (mg/kg diet)</i>								
Copper	3					5.0		
Selenium	0.15					0.7		
Zinc	15		20.0					

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, w/ Vitamins

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

Water soluble vitamin requirements were only available for the rainbow trout and the yellowtail. Again, vast areas for new research needs are apparent.

European sea bass



Considerable research has been conducted with European Sea Bass.

Marine Fish Requirements, FS Vitamins

Marine Fish	Rainbow Trout	Yellowtail	Red Drum	European Sea Bass	Japanese Flounder	Grouper	Asian Sea Bass	Cobia
<i>Fat Soluble Vitamins</i>								
A (IU/kg diet)	0.75mg/kg	5.6		31	2.7	0.9		
D (IU/kg diet)	40μg							
E (mg/kg diet)	50	119	31			115		
<i>Lipids</i>								
n-3 PUFA %		2.0-3.9	0.5-1.0	1.0	1.4	1.0		
Phospholipids %				2.0-3.0	7.0			
18:3n-3 %								

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

- Thiamin Poor appetite, muscle atrophy, convulsions, instability and loss of equilibrium, edema, poor growth, **hyperexcitability to sudden stimulus, with paralysis or aberrant swimming**
- Riboflavin Corneal vascularization, cloudy lens, hemorrhagic eyes, photophobia, dim vision, incoordination, abnormal pigmentation of iris, striated constrictions of abdominal wall, dark coloration, poor appetite, anemia, poor growth, cataracts (bilateral)
- Pyridoxine (B6) 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*,**

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**
- Cyanocobalamin (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, **ascites, steatitis**
- K Prolonged blood clotting, anemia, lipid peroxidation, reduced hematocrit, **hemorrhages in muscle and viscera**

AA and Lipid deficiency signs

Histidine lens cataracts

Methionine lens cataracts

Tryptophan scoliosi, lordosis, **cataracts**

EPA & DHA (**essential fatty acids**) myocarditis, pale/swollen
(fatty) liver, intestinal steatosis, fin erosioin,
bleeding from gills, lordosis, reduced reproductive
potential, shock syndrome

Cholesterol none known for fish, shrimp require cholesterol

Phospholipids **skeletal malformations**

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:

Priority 1

- 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:

Priority 1

- a. Krill
- b. Microbial
- c. Fish byproducts
- d. Squid
- e. Corn and soy
- f. Rapeseed

3. Larval diets & Feed technology

Priority 1

- a. EFA levels and timing
- b. Acceptance & utilization
- c. Transition state
- d. Predigested hydrolytic

CRITICAL RESEARCH NEEDS (2)

4. Nutrigenomics

Priority 2

- a. Genetic engineering
 - b. Nutrient balance and expression
 - c. Gene expression for enzymes
 - d. Simple analytic arrays

5. The Vitamins

Priority 2

- a. Reliable assay techniques
 - b. FS load & effect levels
 - c. WS efficiency levels

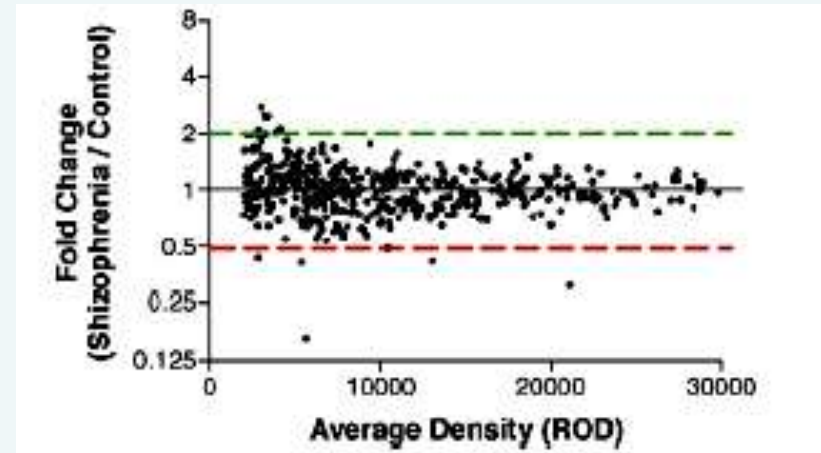
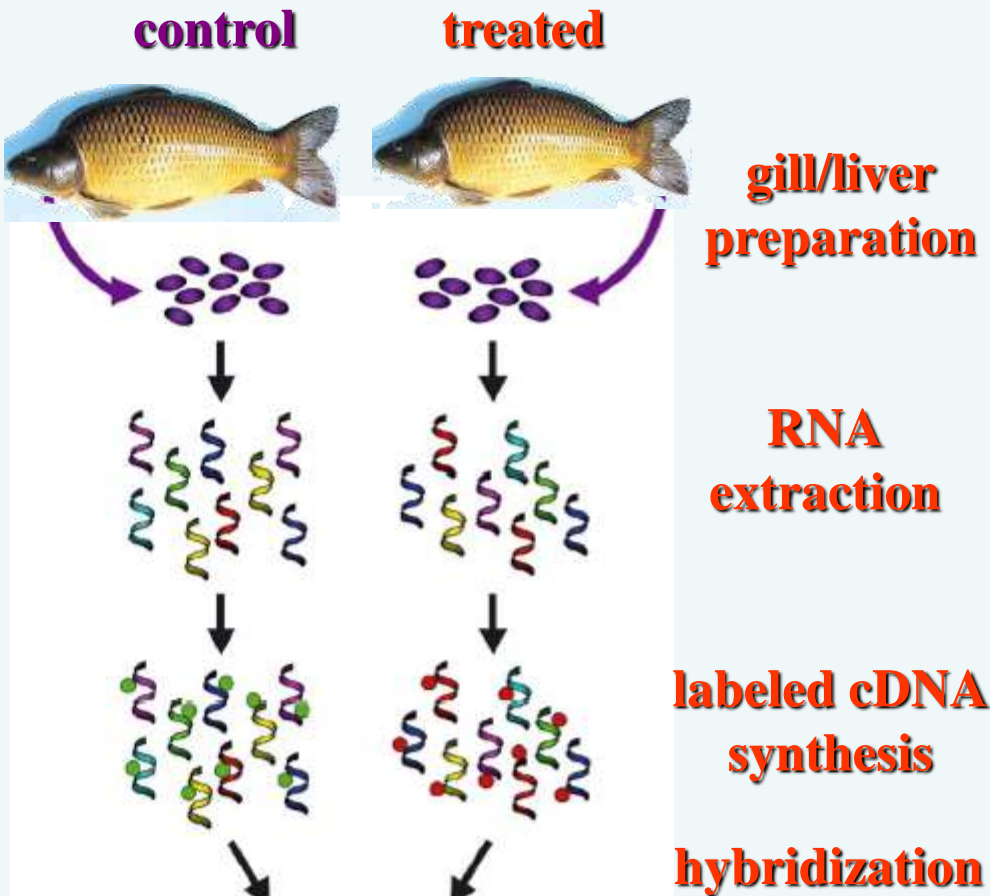
6. Anti-nutrients

Priority 3

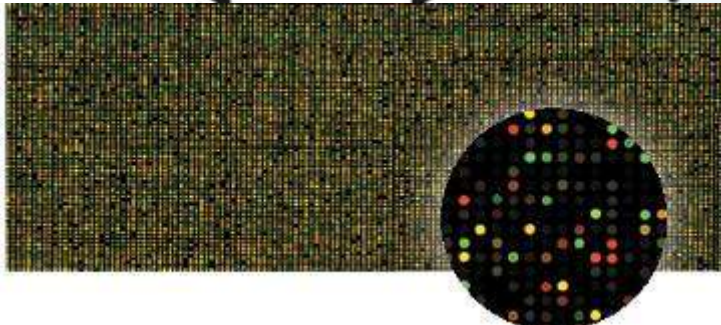
- a. Enzyme inhibitors
 - b. Cross reactions
 - c. Fiber types
 - d. Mycotoxins

Genetic engineering and gene expression for enzymes are a rapidly new area for research.

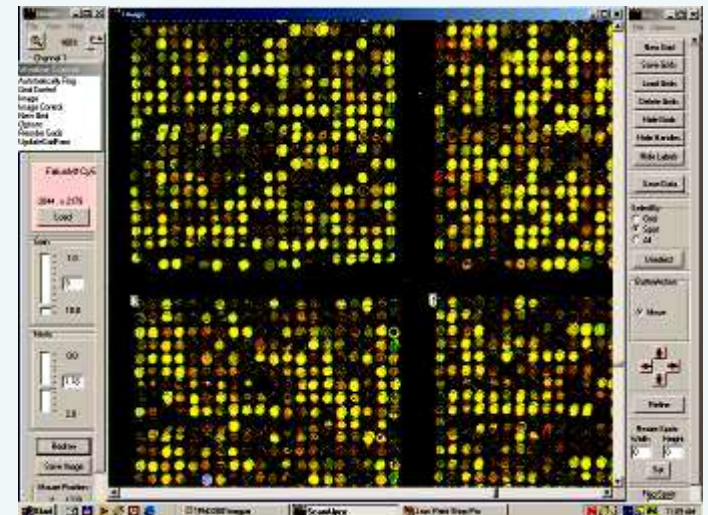
General outline of the DNA-microarray protocol



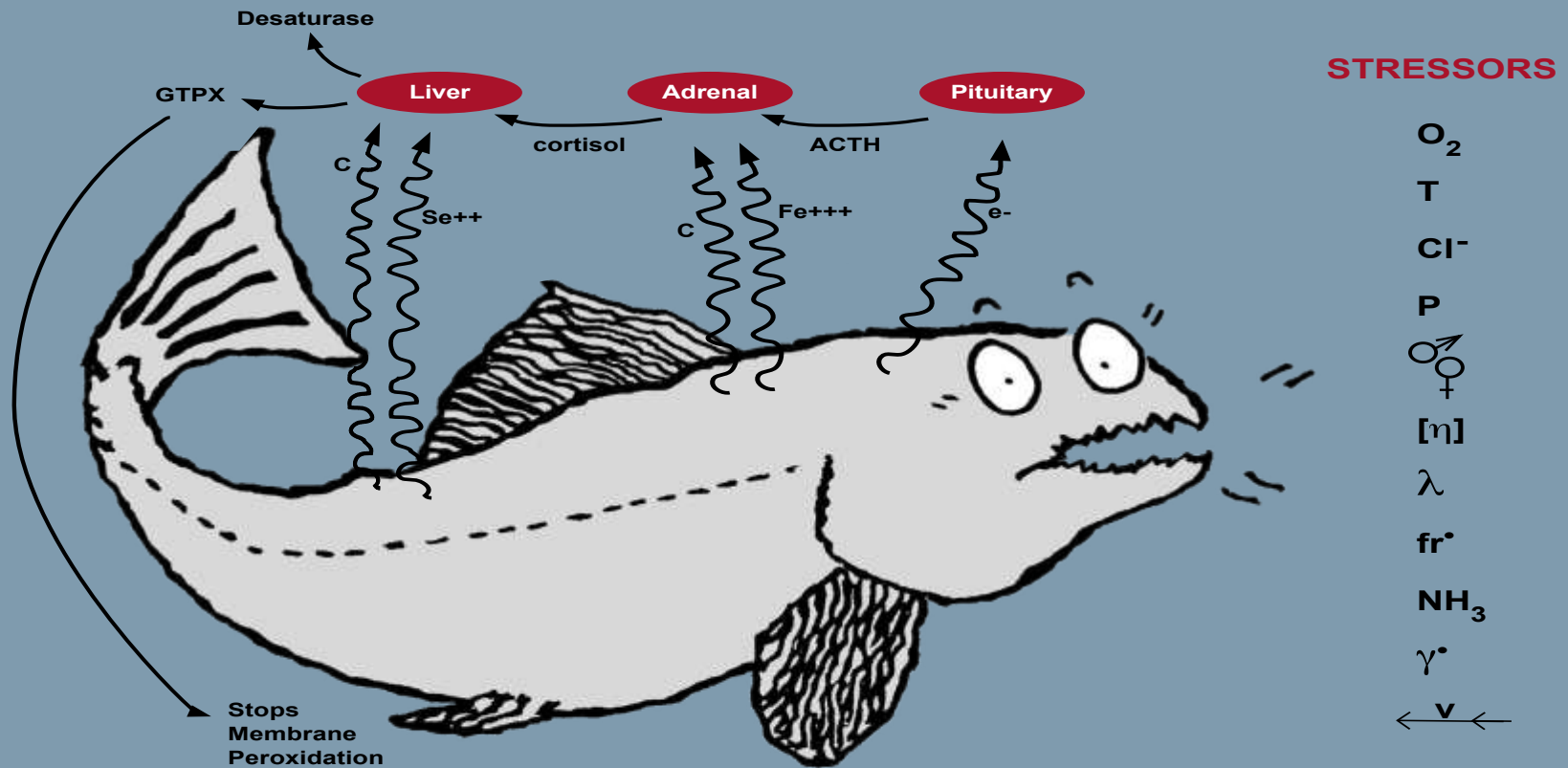
data analysis



dataprocessing



The DiStressed Fish



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

SPONSORS

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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.