NUTRITIONAL STRATEGIES TO ENHANCE SUSTAINABILITY AND EFFICIENCY OF THE US AQUACULTURE INDUSTRY

Catfish in Mississippi

Trout in Idaho

Salmon in Maine

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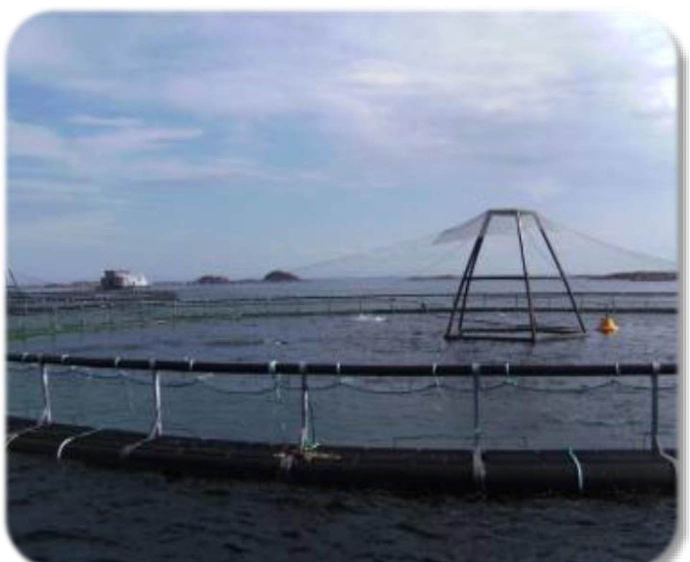
- **Fish compared to livestock and poultry**
- **Global and USA aquaculture production**
- **Challenges and opportunities for sustainable aquaculture feeds**



Fish differ from livestock in several key ways

- **Fish live in water**
  - Neutrally buoyant so there is no need for a large skeleton or muscles to oppose gravity
  - Fish can excrete nitrogenous waste as ammonia via the gills, so lower energy cost for metabolism
  - Fish are cold-blooded, so no energy cost to maintain body temperature
- **Fish reproduction differs from livestock or birds**
  - Many offspring: 2500-5000/trout; millions for marine fish
  - External fertilization – many crosses for selective breeding
- **Aquatic and terrestrial food webs differ**
  - Land webs are based on seeds (grains) and leaves (starch)
  - Aquatic webs are based on algae and zooplankton (lipid)

These factors affect fish farming

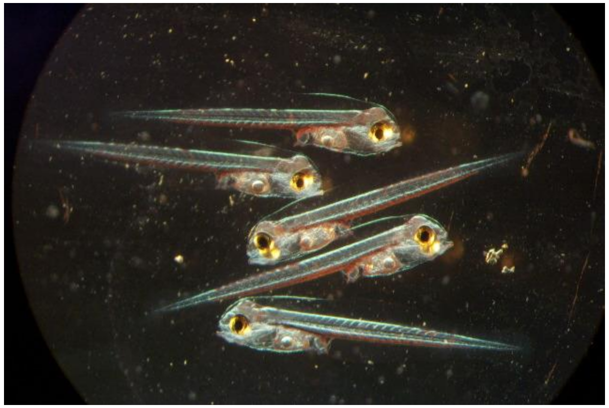
- **Farmers must manage the aquatic rearing environment (water quality management)**
  - Oxygen levels, waste accumulation, stocking density
  - Disease treatment options are limited to vaccination - sick fish don't eat
- **Nearly all species eat fish or zooplankton**
  - Most high-value fish are carnivores (piscivores or insectivores) compared to farm animals that are omnivores (pigs, chickens) or herbivores (ruminants)
  - This greatly affects feed formulations for farmed fish
- **Over 200 species of fish are farmed**
  - Species differ in diet, rearing requirements, health management

Advantages of fish compared to livestock

- Short life cycle and many offspring
- Reach harvest size quickly
  - 105-130 days for shrimp (about 1 ounce live weight)
  - 12 months for tilapia or trout (2 lb fish)
  - 18-24 months for salmon (5-8 lbs)
- Very efficient converters of feed to weight gain
- Yield of edible product is high
  - 30-50% of live weight is fillet; all high quality

Disadvantages of fish compared to livestock

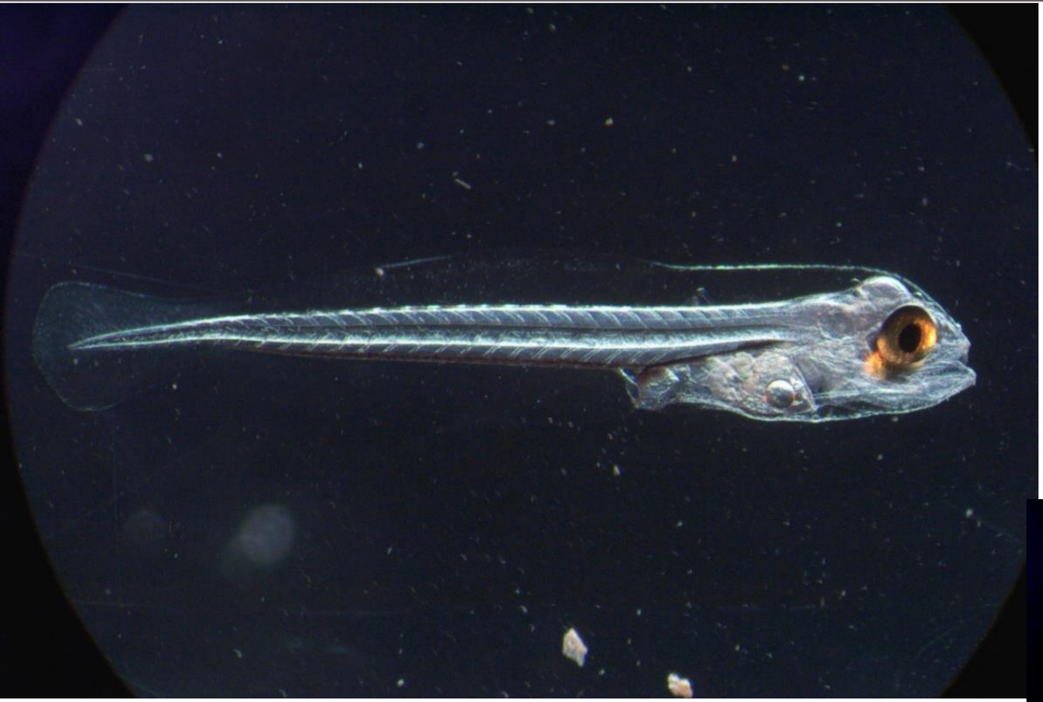
- **Fish live in water**
  - **Water quality issues (too hot, too cold, polluted)**
    - **Suitable freshwater resources are limited and fully utilized**
- **Offspring (larvae) of many species are tough to rear**
  - **Fragile, small and often have immature digestive tract**
    - **Many species must be fed live food at first feeding**



Walleye fry

Halibut fry

Rockfish larvae



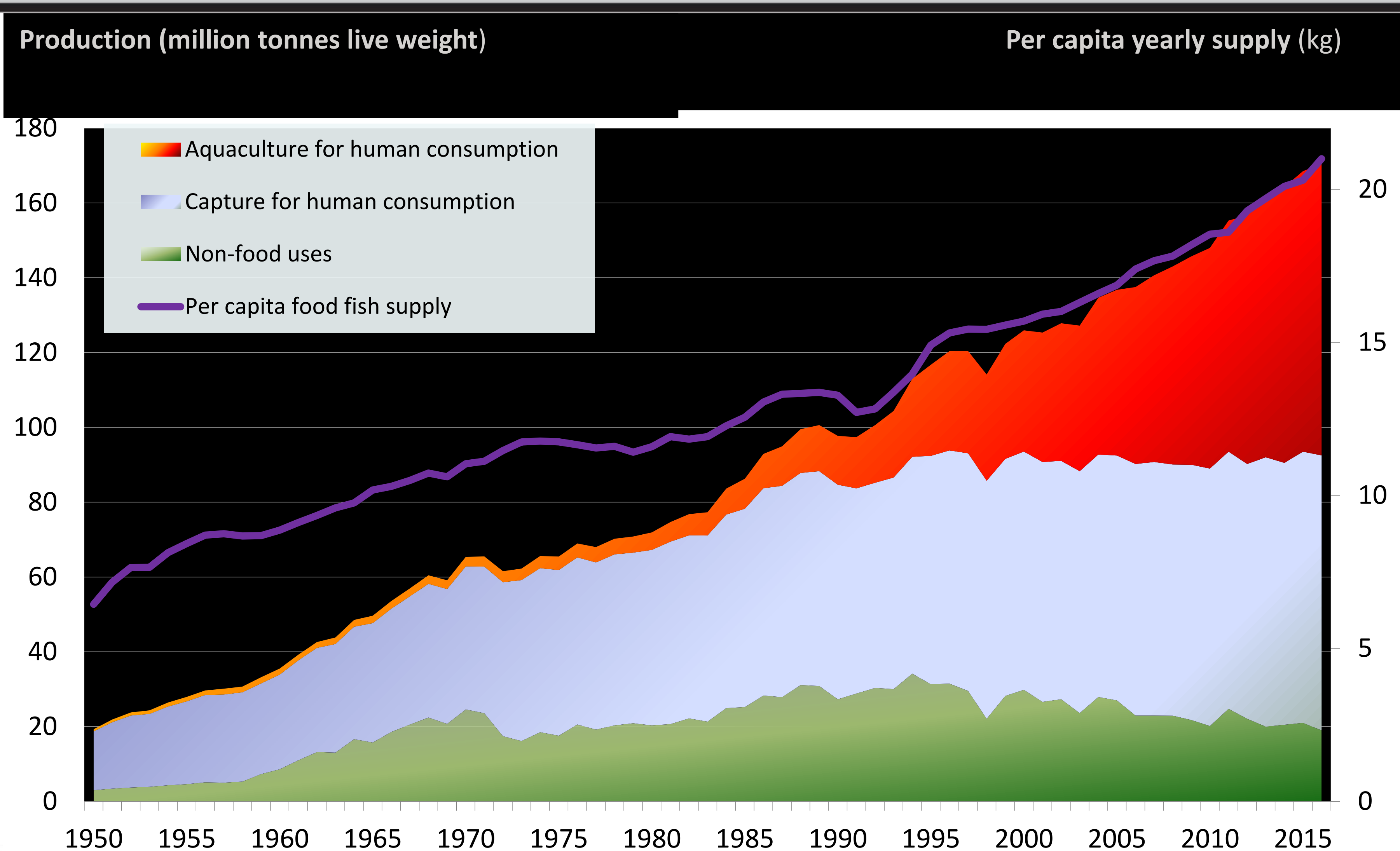
At hatch

At six weeks

Scale and scope of aquaculture

- **A $132 billion global business growing at ~6% per year worldwide (lower growth rate in North America & Europe)**
- **Supplies >50% of consumable fishery products (traditional fishing supplies the remainder)**
- **Major source of income and foreign exchange for many countries**
- **Major source of protein for over 3 billion people**

Global seafood production and utilization



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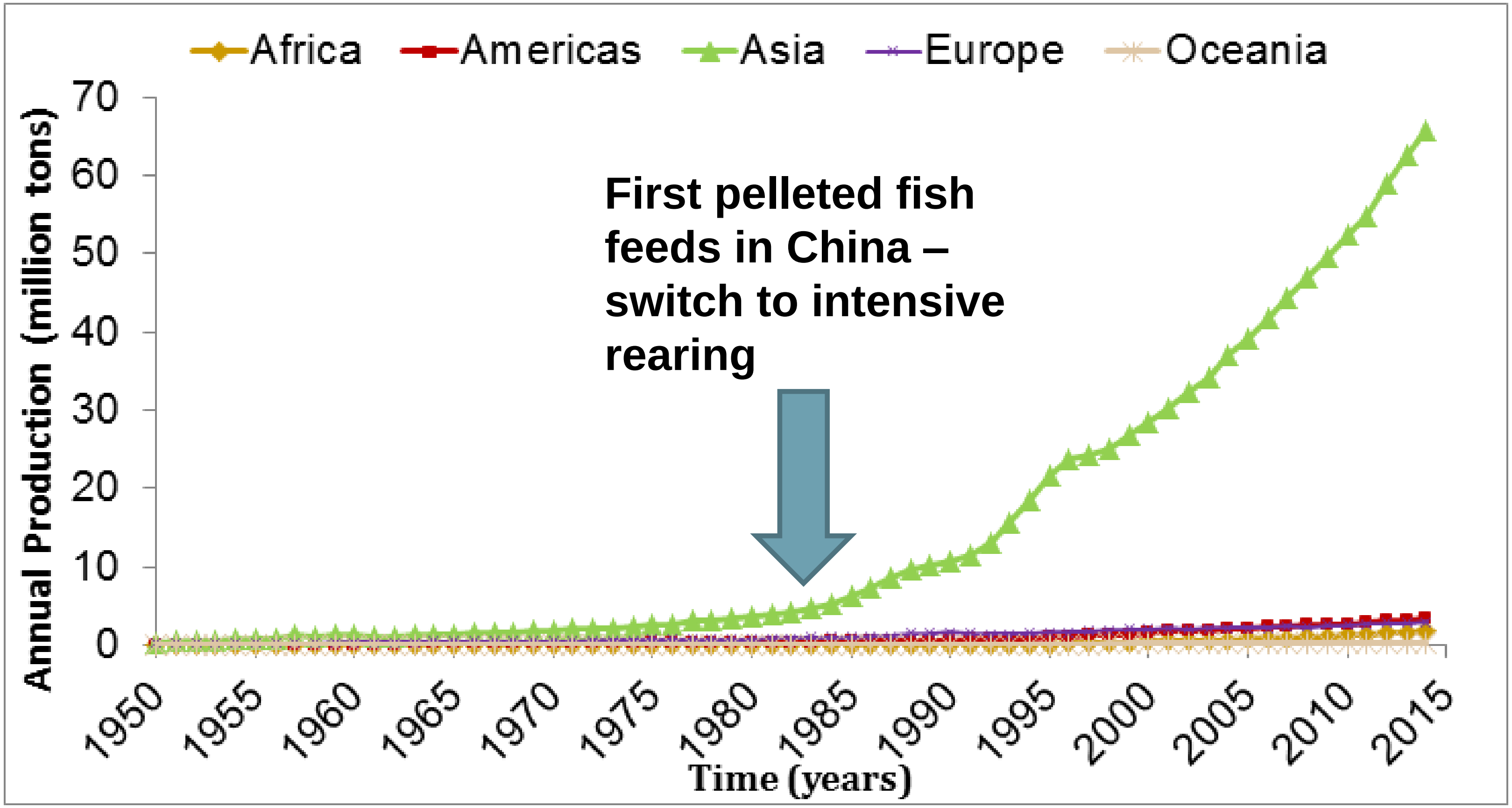
Aquaculture production by region (excluding plants)



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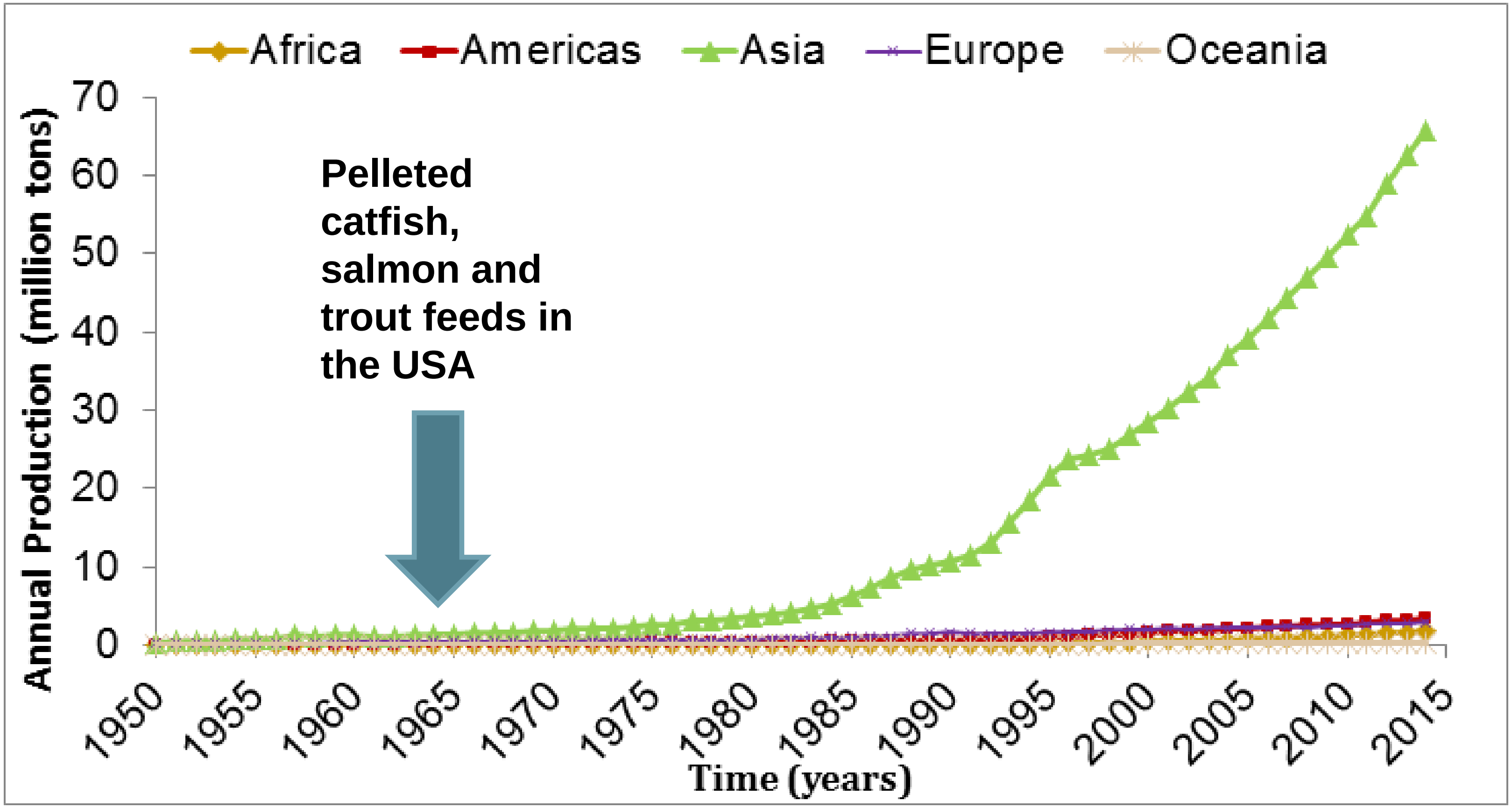

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Aquaculture has become a large international business

- Family livelihood
- Low technology
- Labor intensive
- Low yields/hectare
- Polyculture

traditional aquaculture

- High technology
- Profit-driven
- High energy & feed inputs
- Monoculture
- High yields/hectare

industrial aquaculture

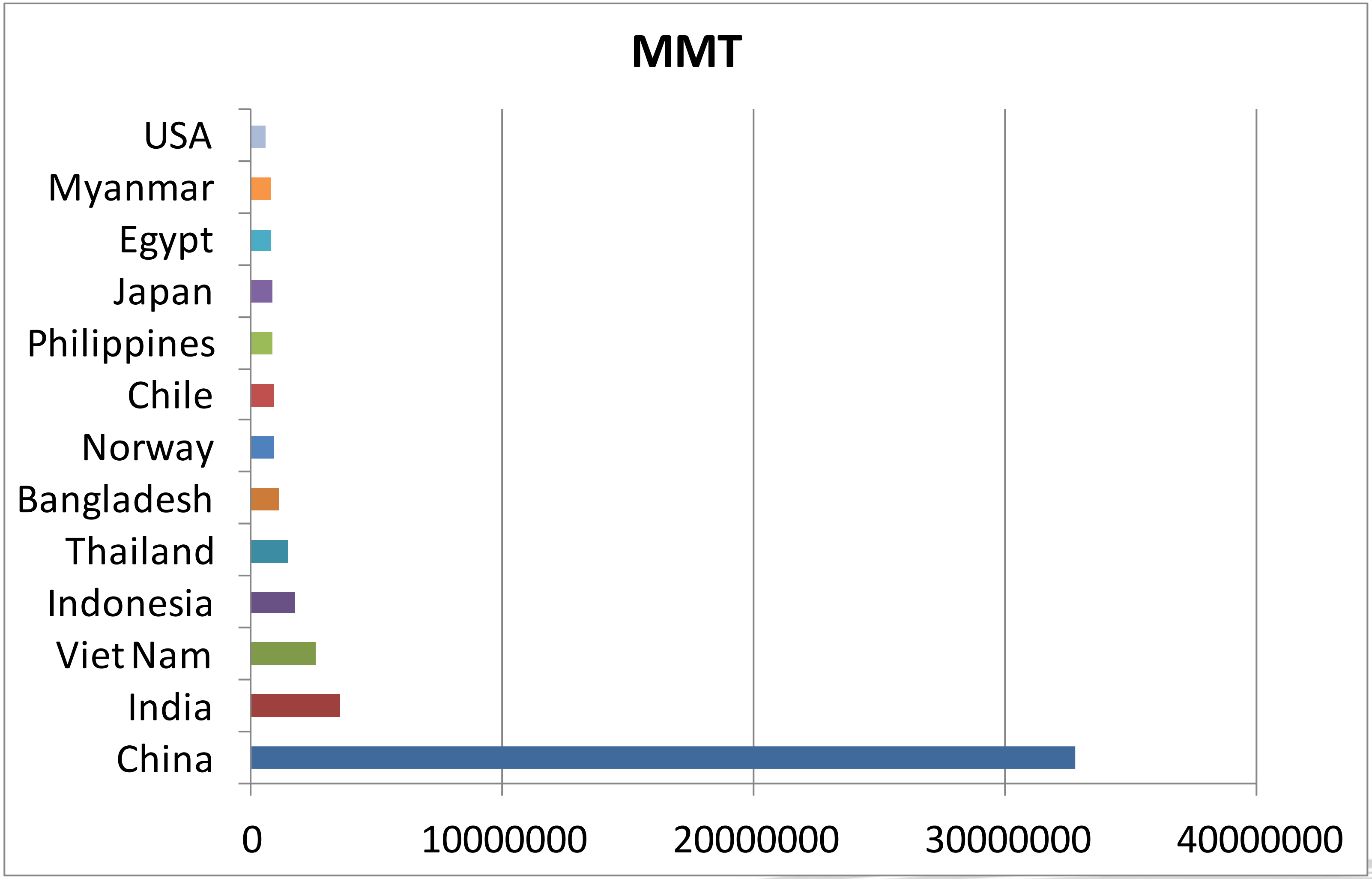
What enabled aquaculture growth?

- Development of effective feeds that supply all essential nutrients for growth and health
- Development of vaccines against common bacterial diseases
- Advances in fish reproduction and larval fish rearing
- Technologies to support intensive fish culture

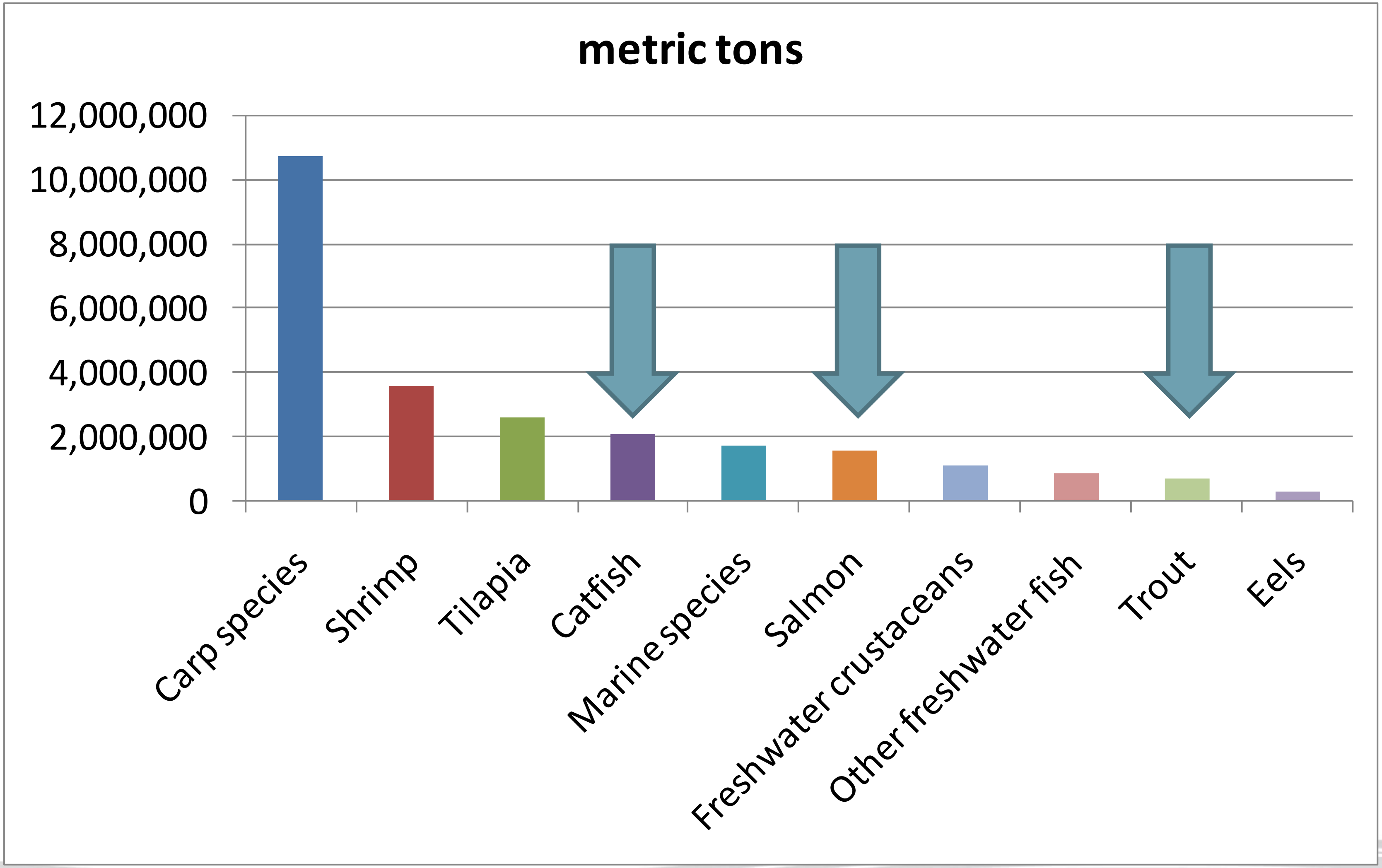
Leading aquaculture producing countries

Countries	Production, metric tons (2008)	Percent of total	Growth rate (%) 1990-2008
China	32,736,000	62.3	9.4
India	3,479,000	6.6	7.1
Viet Nam	2,462,000	4.7	16.4
Indonesia	1,690,000	3.2	7.0
Thailand	1,347,000	2.6	9.0
Bangladesh	1,006,000	1.9	9.6
Norway	844,000	1.6	10.0
Chile	843,000	1.6	19.8
Philippines	741,000	1.4	3.8
Japan	732,000	1.4	-0.5
United States	~500,000	0.95	2.6

Aquaculture production by country



Aquaculture production by species groups



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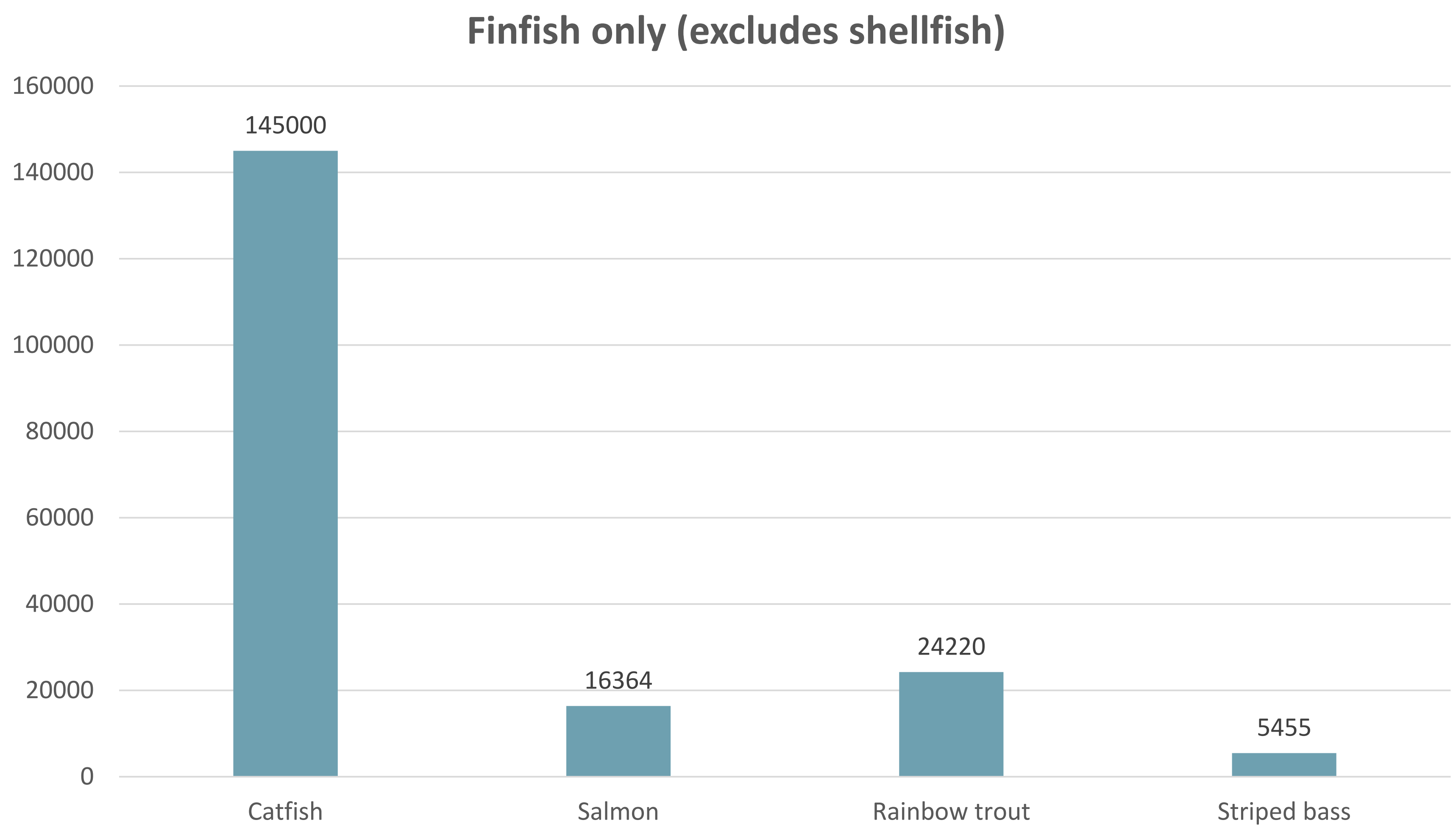
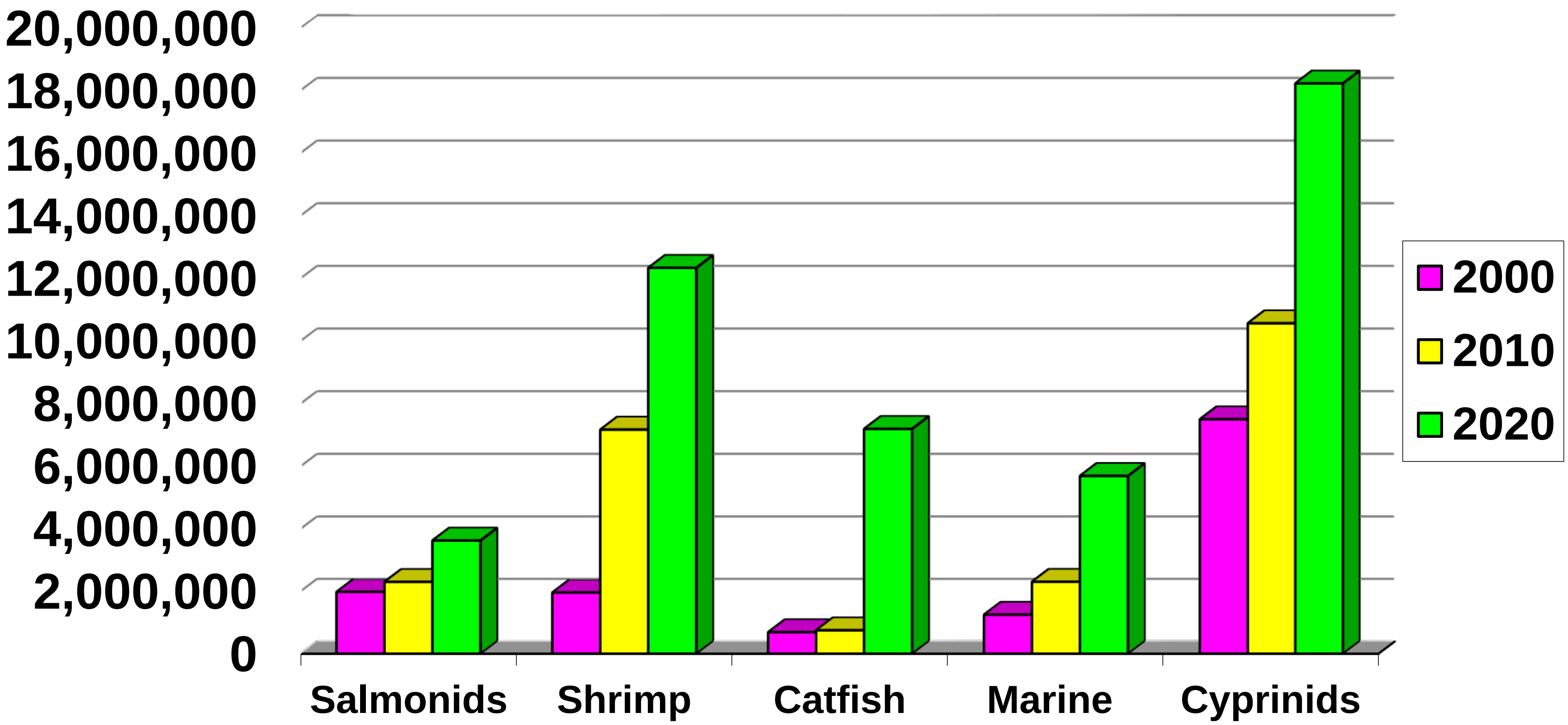
US aquaculture production (mt)



US aquaculture and seafood consumption

- US imports 90% of its seafood
- Catfish producers are challenged by imports of Pangasius (Asian catfish)
- Salmon production limited to Maine as Washington state cuts salmon farming
- Rainbow trout is limited by freshwater supplies
- Marine fish (not salmon) aquaculture is limited to Hawaii

World aquafeed production (mt)



Aquaculture's fishmeal problem

- Annual production is about 5 million metric tons
  - Aquaculture feeds use 70-80% of this amount
  - Demand-driven price increases since 2007 are 2-3x
- Aquaculture production is expected to double by 2030
- Fish feed production will also have to double
  - Not enough fishmeal using current formulations
- Need to replace fishmeal with alternative proteins
  - Plant protein concentrates from soy, corn, wheat, barley, sunflower, etc.
  - Recovered seafood processing wastes
  - Land animal proteins (rendered products)
  - Single-cell proteins (bacterial, yeast)

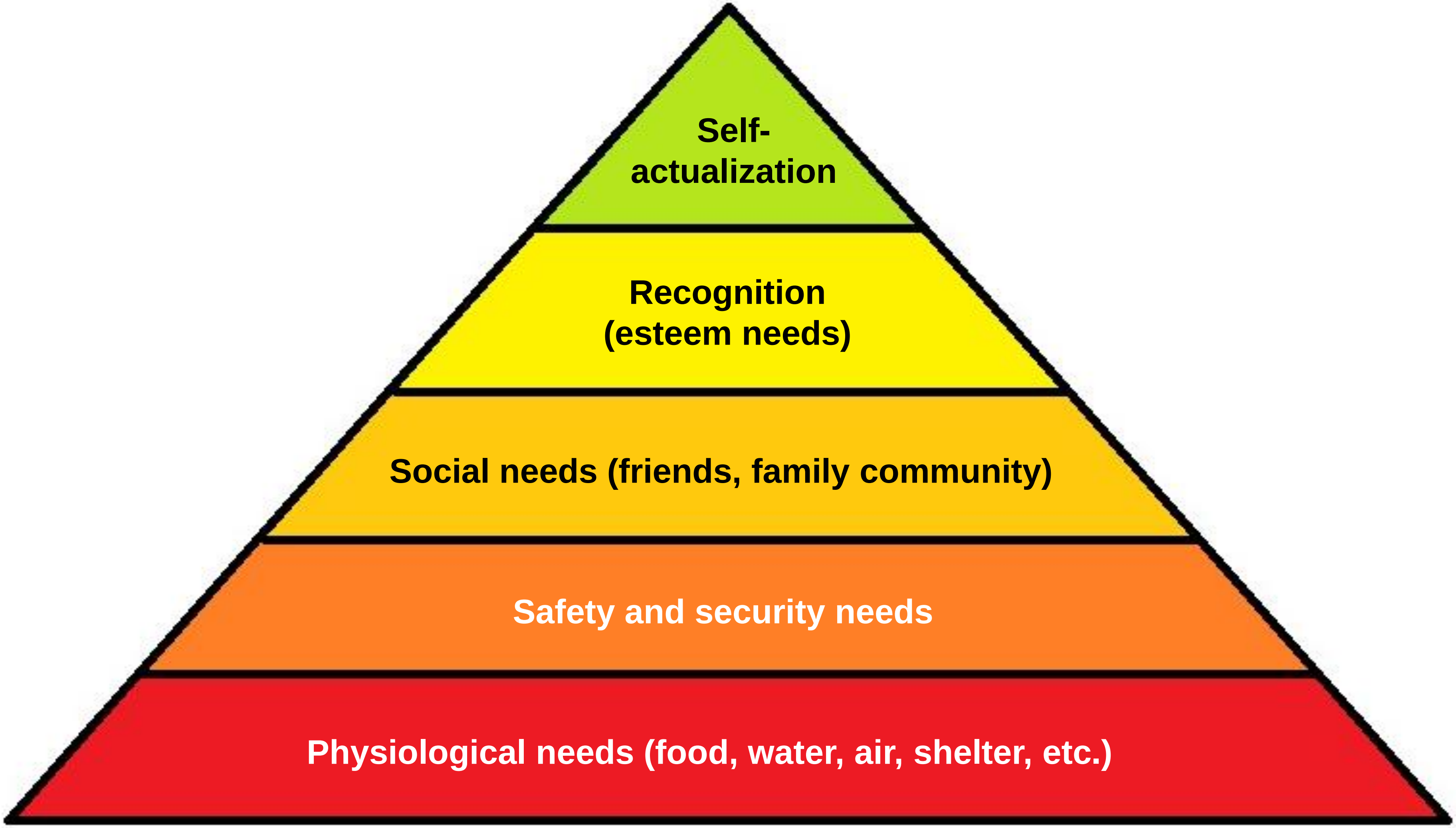
Farmed fish in the US and their feeds

- **Omnivores (channel catfish and tilapia)**
  - Long digestive tracts, >5 times body length
  - Thrive on soy-corn feeds, 28-32% crude protein, low fat
- **Carnivores (piscivores)**
  - Short digestive tracts, roughly similar to body length
  - Need >38% protein, with higher levels for fry and fingerling
  - Lipid levels in feeds are 20-30%, depending on species
  - Feeds typically contain fishmeal, land animal proteins and protein concentrates

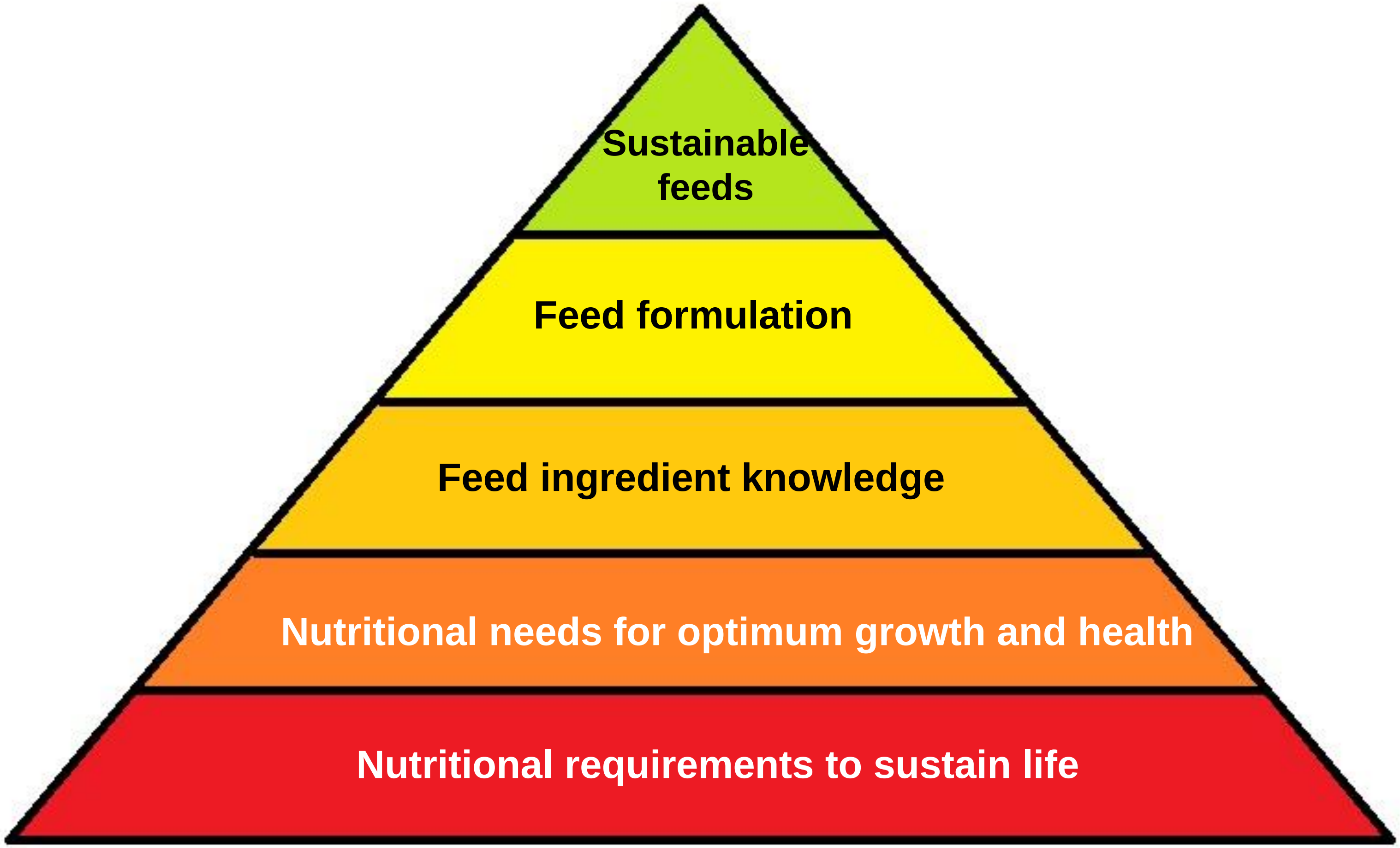
Can carnivorous fish become vegetarians?

- Fish eat other fish or invertebrates in nature
  - Fishmeal is the perfect protein for farmed fish
- However, fish require essential nutrients in the diet, not specific ingredients
- The challenge is that we do not yet know the optimum dietary nutritional requirements of most farmed fish

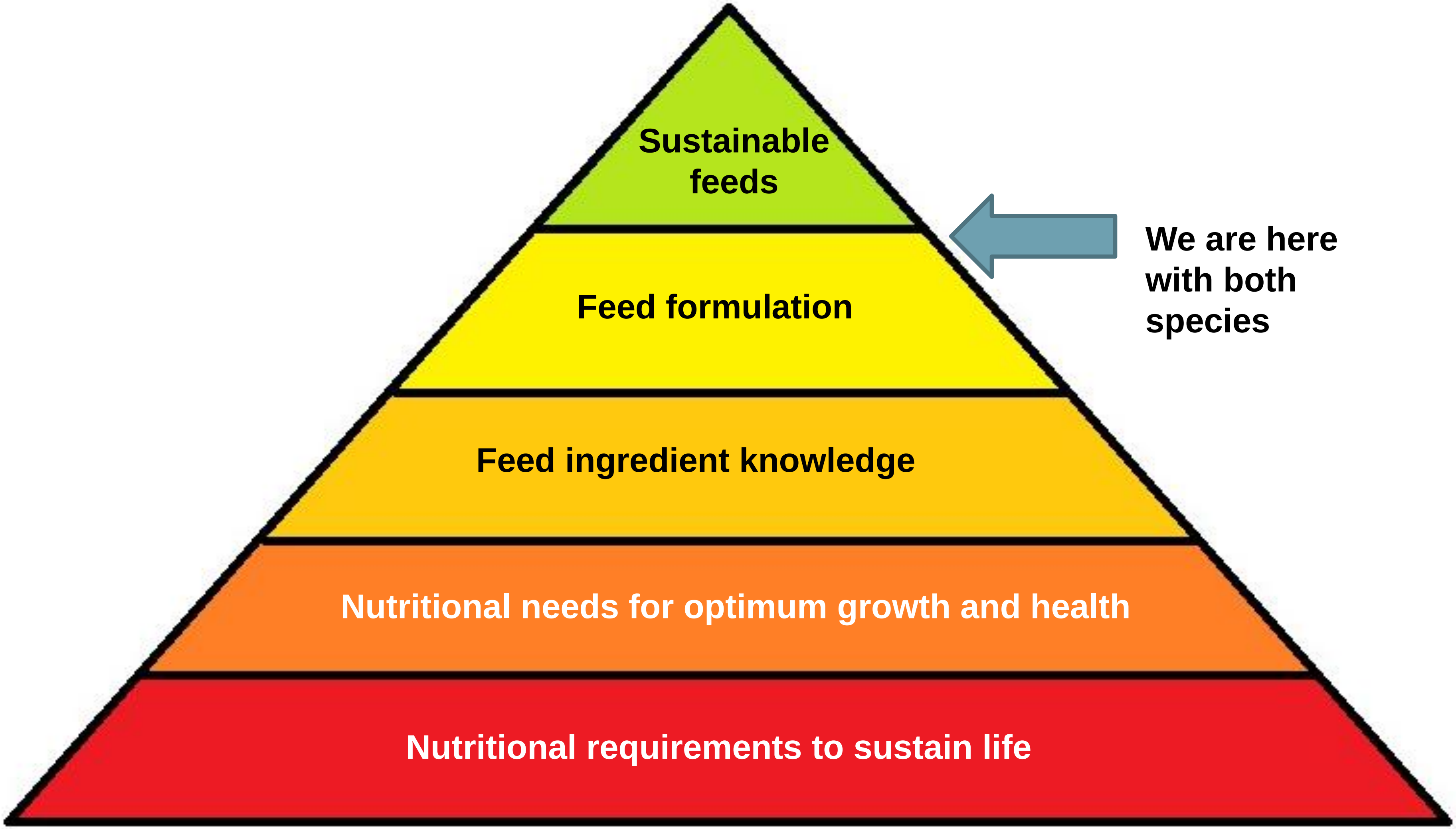
Maslow's 'Hierarchy of Needs'



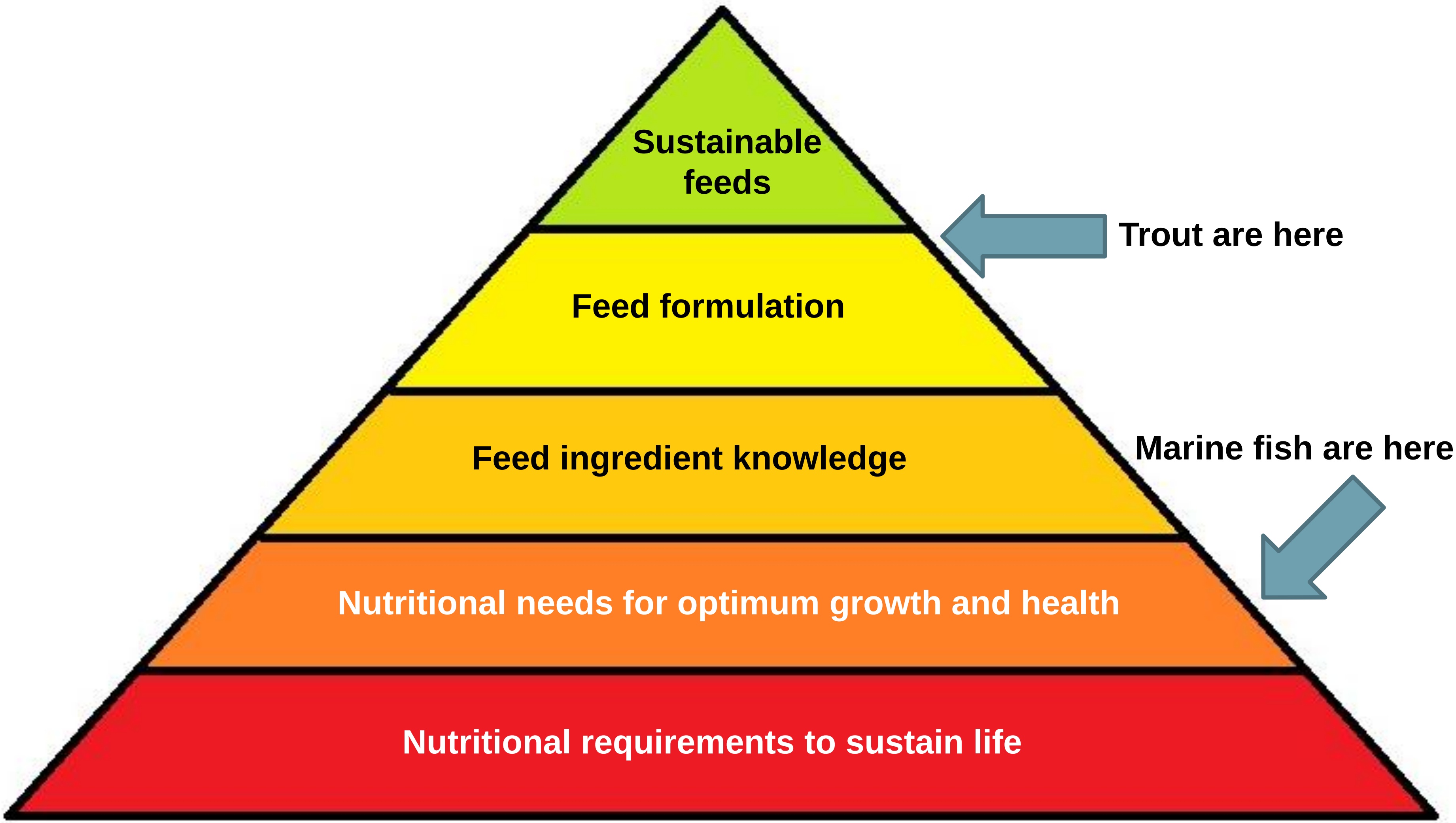
Hardy's 'Hierarchy of Feeds'



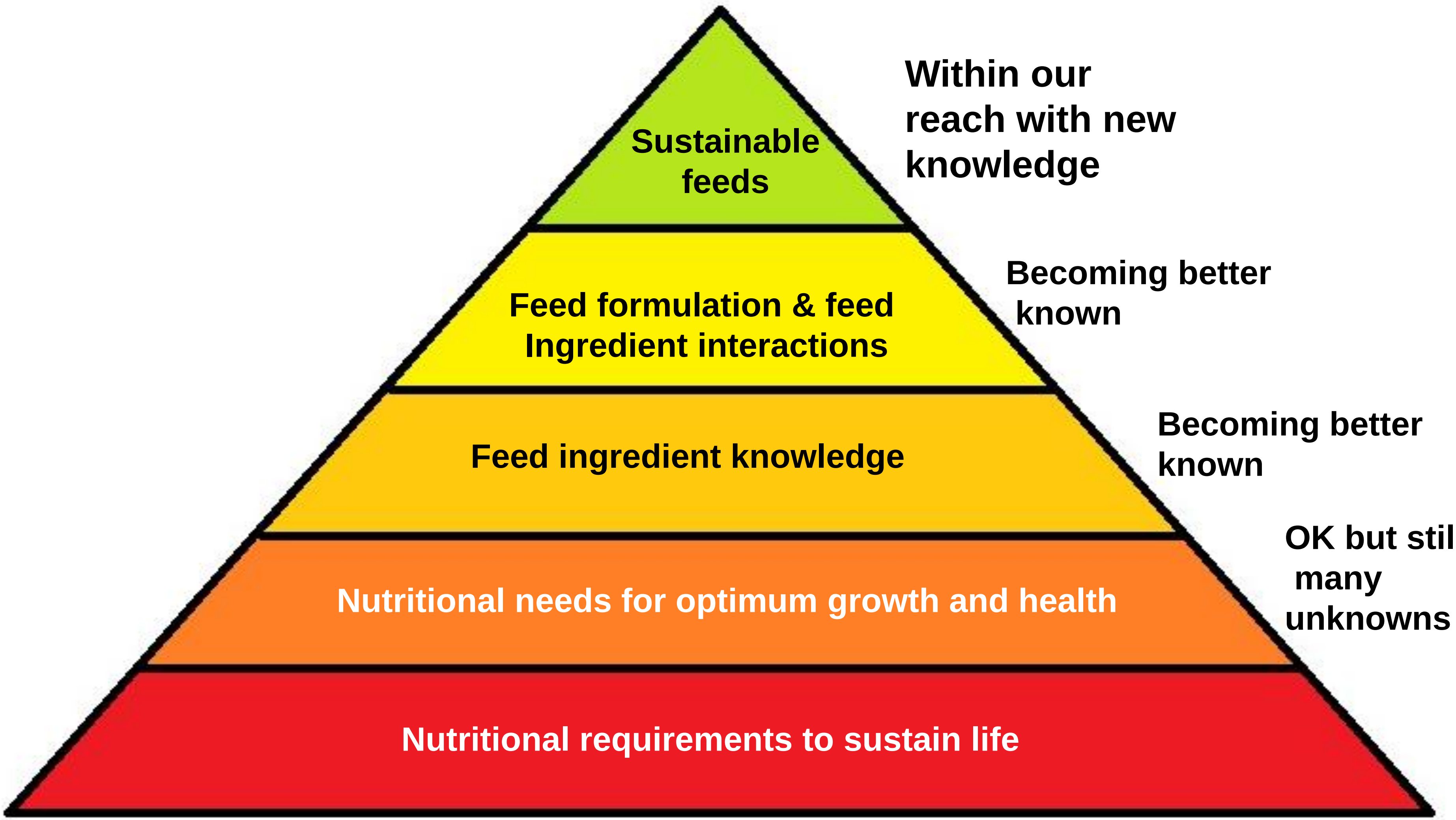
Contrasting trout with catfish



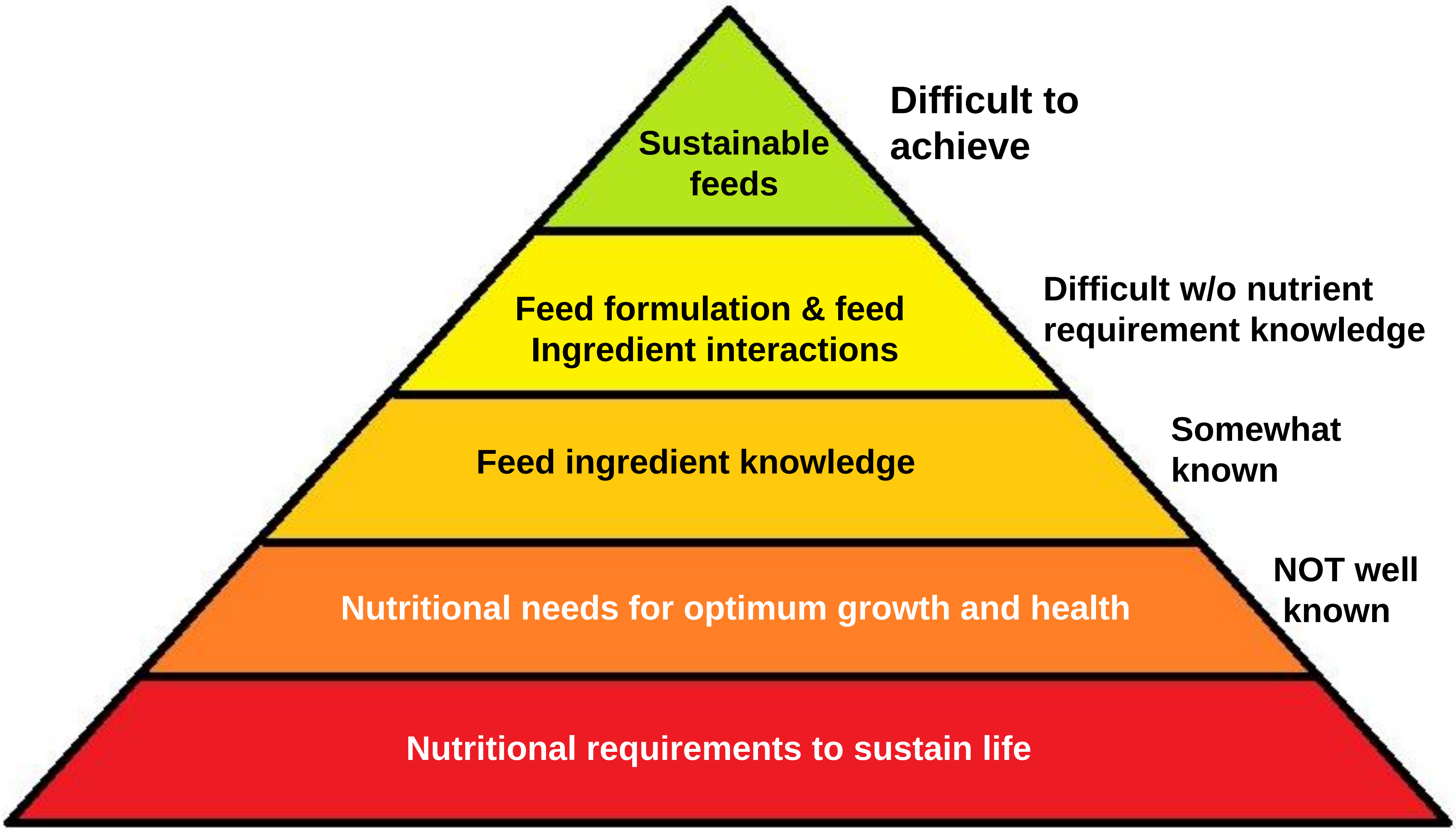
Contrasting trout with marine species



Nuanced situation with trout

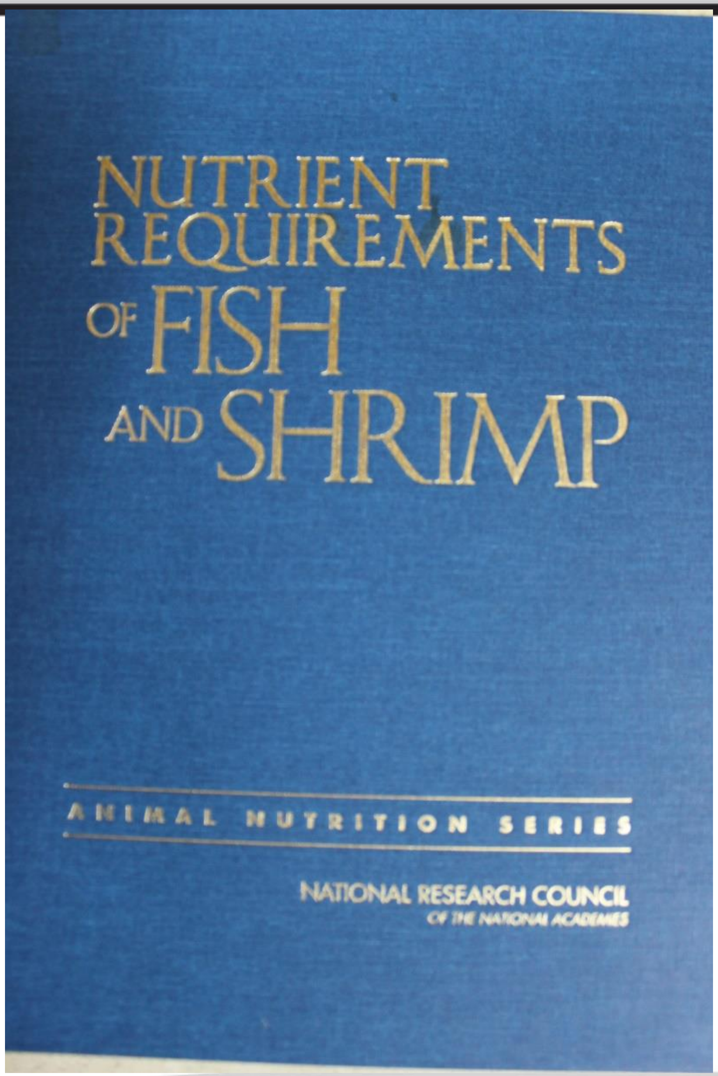


Situation with marine fish



Differences between trout and other species

Lack of data limits advances in feed formulation



Latest version published in 2011

Freshwater Fish Requirements, amino acids

AMINO ACIDS	Channel catfish	Rainbow trout	Pacific salmon	Common carp	Tilapia
Arginine	1.20	1.50	2.20	1.70	1.20
Histidine	0.60	0.80	0.70	0.50	1.00
Isoleucine	0.80	1.10	1.00	1.00	1.00
Leucine	1.30	1.50	1.60	1.40	1.90
Lysine	1.60	2.40	2.20	2.20	1.60
Methionine	0.60	0.70	0.70	0.70	0.70
Methionine, cystine	0.90	1.10	1.10	1.00	1.00
Phenylalanine	0.07	0.90	0.90	1.30	1.10
Phenylalanine, tyrosine	1.60	1.80	1.80	2.00	1.60
Threonine	0.70	1.10	1.10	1.50	1.10
Tryptophan	0.20	0.30	0.30	0.30	0.30
Valine	0.80	1.20	1.20	1.40	1.50

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Marine Fish Requirements, amino acids

	Yellowtail	Red Drum	European Sea Bass	Japanese Flounder	Grouper	Asian Sea Bass	Cobia
Arginine	1.6	1.8	1.8	2.0		1.8	
Histidine							
Isoleucine							
Leucine							
Lysine	1.9	1.7	2.2	2.6	2.8	2.1	2.3
Methionine	0.8	0.8		0.9		0.8	0.8
Methionine+ cystine	1.2	1.2	1.0			1.2	1.1
Phenylalanine							
Threonine		0.8	1.2				
Tryptophan			0.3				
Valine							
Taurine	R	R	0.2	R	R	R	R

Freshwater Fish Requirements, Vitamins

	Channel catfish	Rainbow trout	Pacific salmon	Common carp	Tilapia
mg/kg dry diet					
Thiamin	1	1	10	0.50	NT
Riboflavin	9	4	7	7	6
Pyridoxine (B6)	3	3	6	6	15
Pantothenic acid	15	20	20	30	10
Niacin	14	10	150	28	26
Biotin	R	0.15	1	1	0.06
Cyanoco-balomine (B12)	R	R	0.02	NR	NR
Folate	1.50	1	2	NR	1
Choline	400	800	800	1500	1000
Myoinositol	NR	300	? ?	440	400
Ascorbic Acid (C)	15	20	? ?	45	20

Marine Fish Requirements, Vitamins

	Yellowtail	Red Drum	European Sea Bass	Japanese Flounder	Grouper	Asian Sea Bass	Cobia
mg/kg							
Thiamin	11						
Riboflavin	11						
Pyridoxine (B6)	12						
Pantothenic acid	36						
Niacin	12						
Biotin	0.67						
Cyanocobalomine (B12)	0.05						
Folate	1.2						
Choline	1000	600					700
Myoinositol	420				350		
Ascorbic acid (C)	43-52	15	20		18	30	45-54

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Freshwater Fish Requirements, Minerals

	Channel catfish	Rainbow trout	Pacific salmon	Common carp	Tilapia
Macro minerals (% diet)					
Calcium	0.45	? ?	R	0.03	0.70
Chlorine	0.17	? ?	NT	NR	0.15
Magnesium	0.04	0.05	NT	0.05	0.06
Phosphorus	0.33	0.70	0.60	0.70	0.40
Potassium	0.26	? ?	0.80	NT	0.2-.03
Sodium	0.06	? ?	NT	NT	0.15
Micro minerals (mg/kg diet)					
Copper	5	3	NT	3	5
Iodine	1.10	1.10	1	NT	NT
Iron	30	? ?	NT	150	85
Manganese	2.40	12	NT	12	7
Selenium	0.25	0.15	R	NT	NT
Zinc	20	15	NT	15	20

Marine Fish Requirements, Minerals

	Yellowtail	Red Drum	European Sea Bass	Japanese Flounder	Grouper	Asian Sea Bass	Cobia
Macro minerals (% diet)							
Chlorine		R					
Phosphorus		0.8	0.7	0.6			
Sodium		R					
Micro minerals (mg/kg diet)							
Copper					5.0		
Selenium					0.7		
Zinc		20.0					

Marine fish nutrient requirements

- For many important farmed fish and shrimp species, quantitative nutrient requirements are not known
- When fishmeal and oil were primary protein and lipid sources in feeds, this was not a significant problem
  - High fishmeal in feeds covered up our ignorance because fishmeal supplied many essential nutrients
- With the shift to plant protein sources, lack of knowledge becomes critical
  - Impossible to rationally formulate nutritionally balanced feeds

Why is this important?

- **With the shift to plant protein sources, lack of knowledge becomes critical**
  - **Impossible to rationally formulate nutritionally balanced feeds based on available nutrient content if we don’t know nutritional requirements**
- **Replacing fishmeal with plant proteins in fish feeds is challenging**
  - **Fishmeal is a complex material containing essential nutrients (amino acids, fatty acids, minerals and vitamins), biologically active compounds and high energy**
  - **Plant proteins lack many minerals, amino acid profiles differ, biologically active compounds are generally bad for fish**

Modified salmon feeds for marine species

- **This approach simply has not worked**
- **Marine fish fed low fishmeal salmon feeds exhibit signs of oxidative damage and liver dysfunction**
- **Attempts by the commercial sector to correct these problems made things worse**
  - **Over-fortified with iron and vitamin E levels**
  - **This worsened oxidation issues**
- **A holistic approach to feed formulation is needed**

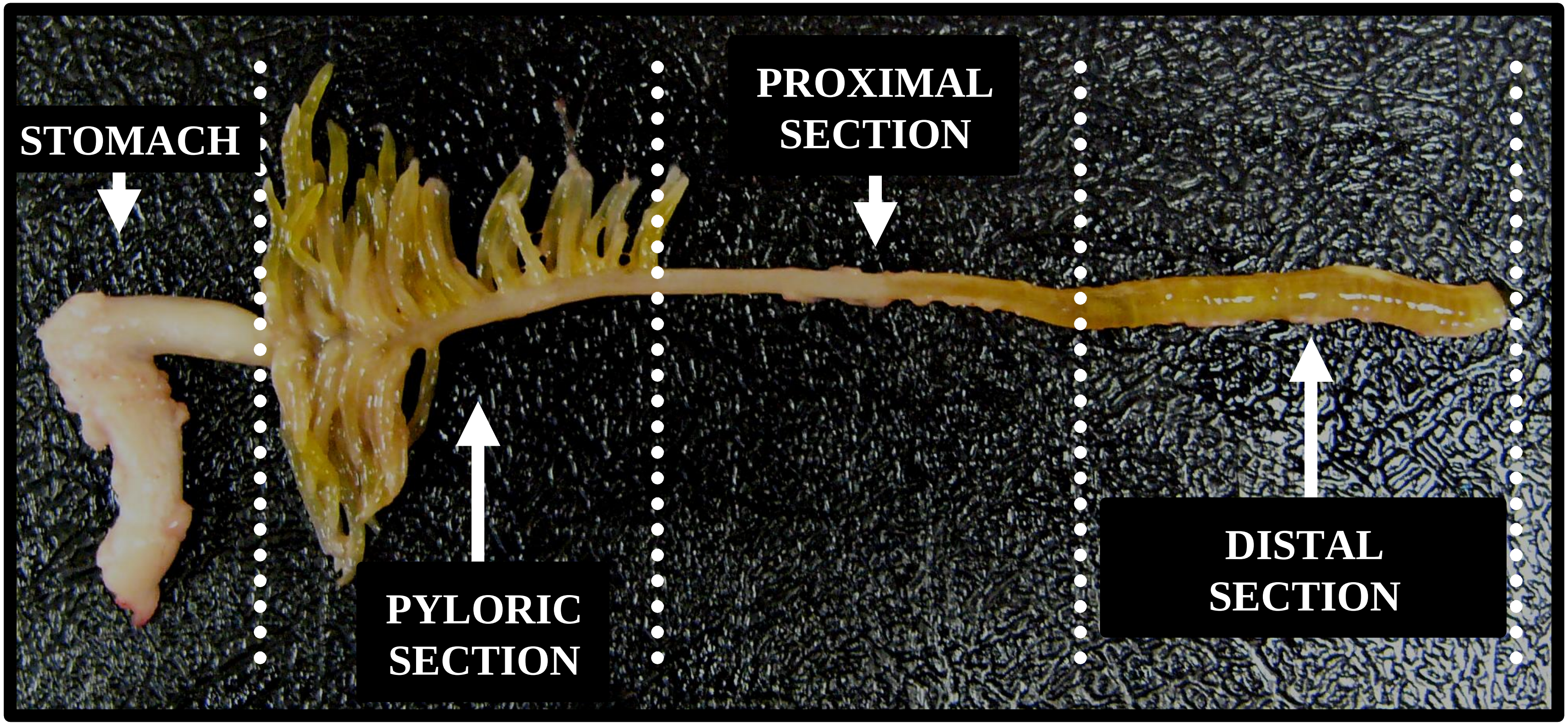
Plants play defense

- **Plants employ strategies to discourage seed consumption by birds and animals**
  - Compounds that taste bad and reduce feed intake
  - Compounds that interfere with metabolism or digestion
    - Trypsin inhibitors in soy
    - Goiterogens in canola that interfere with thyroid function
    - Gossypol in cottonseed
    - Lectins
  - Compounds that interact with other nutrients
    - Phytic acid
    - Saponins, lectins
  - Compounds that cause intestinal enteritis in fish, infants & piglets
- **Fish are more sensitive to these antinutrients than pigs, chickens, rats, etc.**

Example - soybean meal in fish diets and enteritis

- **Enteritis is an inflammatory condition in the intestinal lining resembling colitis**
  - **Progressive condition (gets worse over time)**
  - **Dose-dependent condition with a threshold soy level in diet**
  - **Not evident in trout after 12 weeks, but present after 24 weeks of feeding**
  - **Characterized by morphological changes in intestinal villi**
- **Not all fish species develop enteritis**
  - **Easily induced in salmon and trout**
  - **Observed in sea bass and sea bream**
  - **Catfish and tilapia are not affected**

SBM-induced enteritis located at first part of the distal intestine



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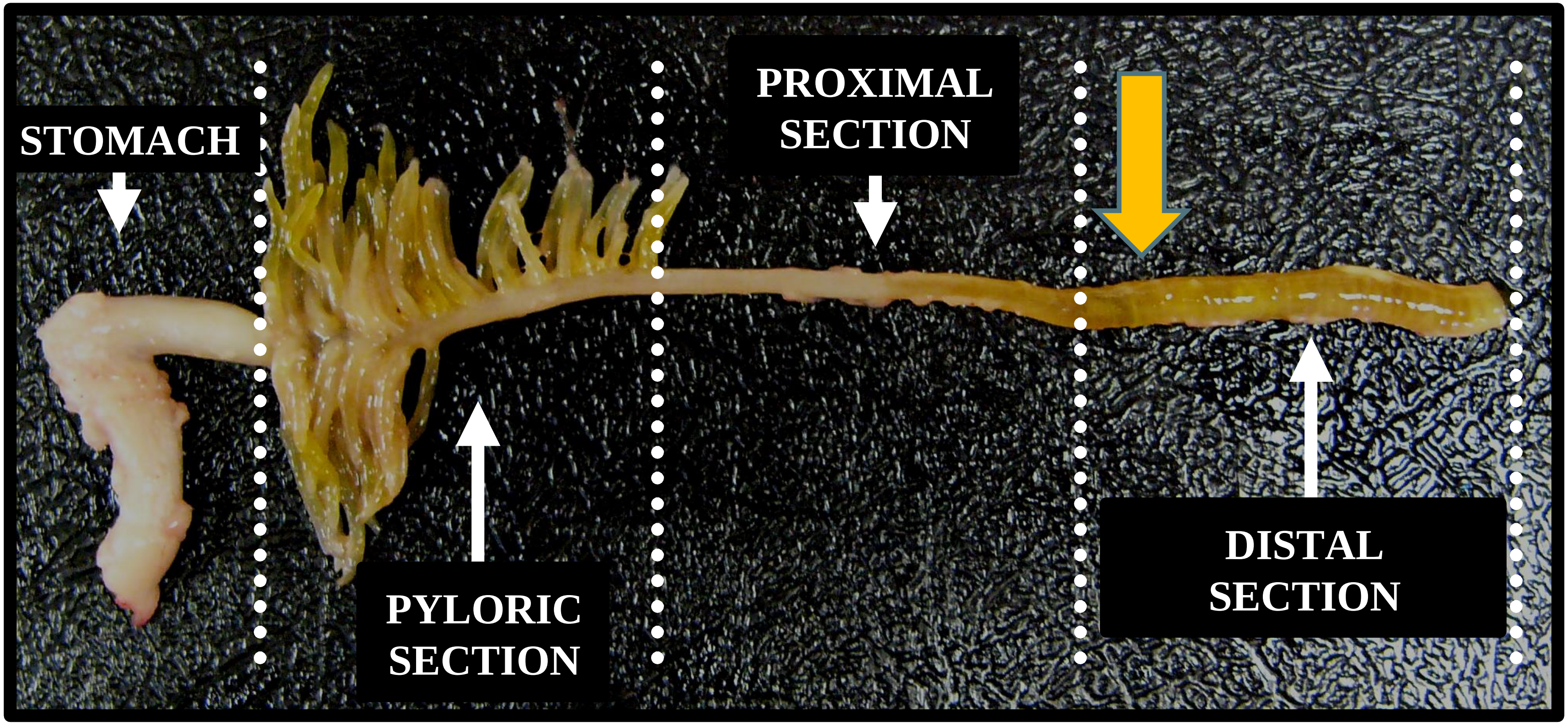
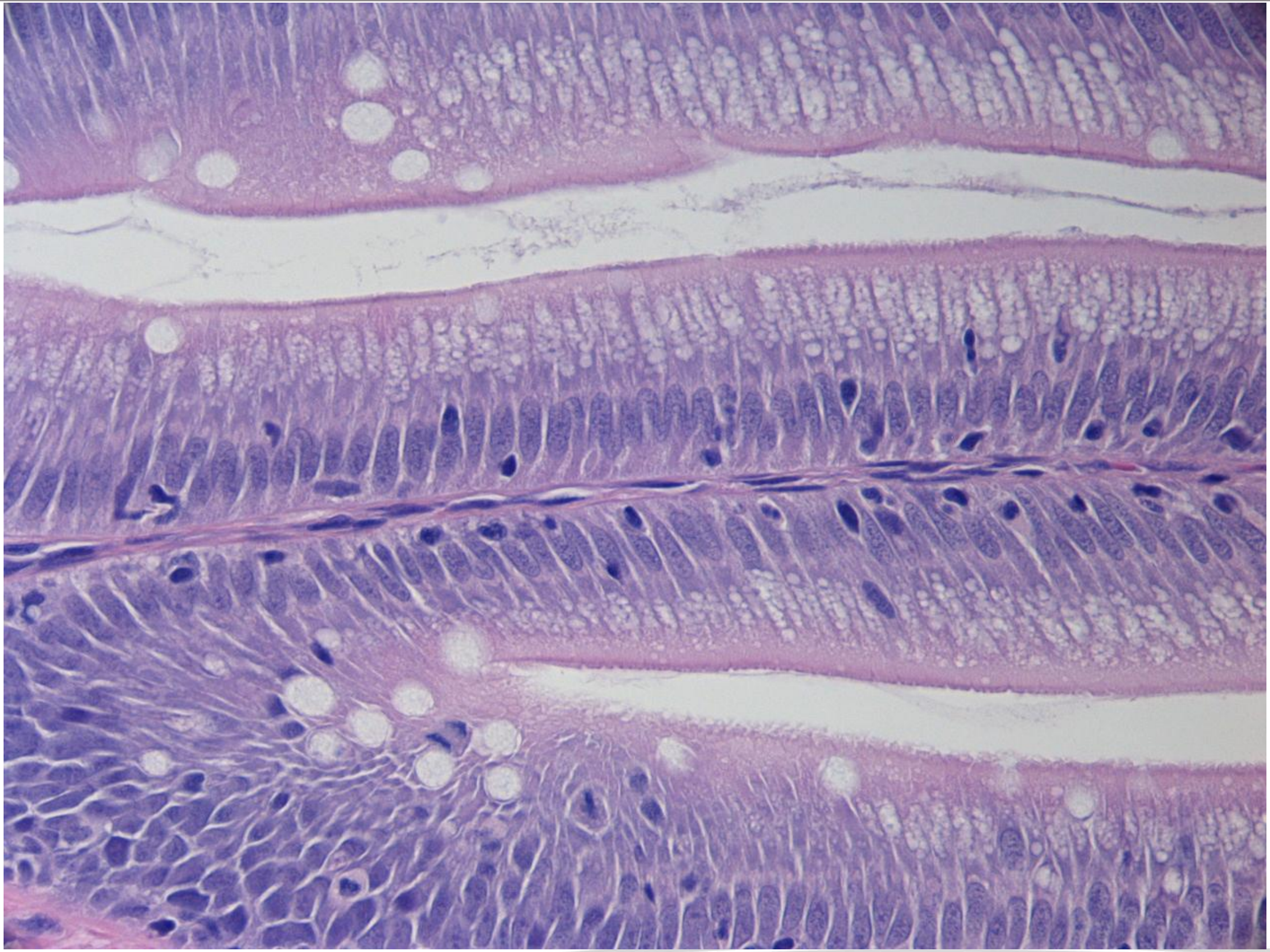


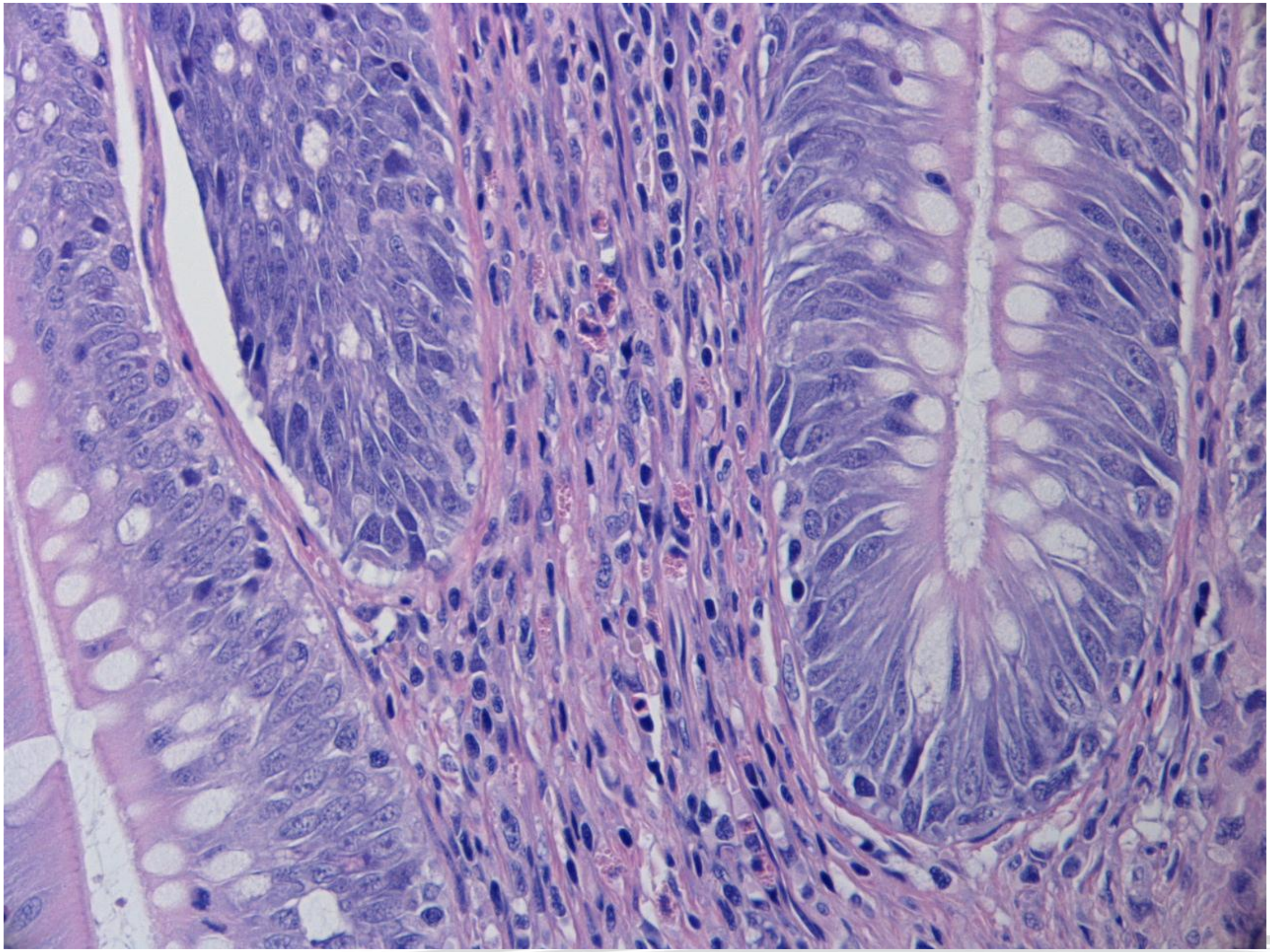
Normal villi – grade 1

H1 H&E staining, 400x, LP grade 1
Base of the crypt is to the left side of the picture; intestinal lumen is to the right



Severe enteritis – grade 4

H66 H&E staining, 400x, Lamina propria grade 5; TIC grade 4
Intestinal lumen is towards the top of the image.
Expansion of the lamina propria of the villi with infiltrates of mixed inflammatory cells (lymphocytes, eosinophilic granular cells and fewer macrophages and rare plasma cells.



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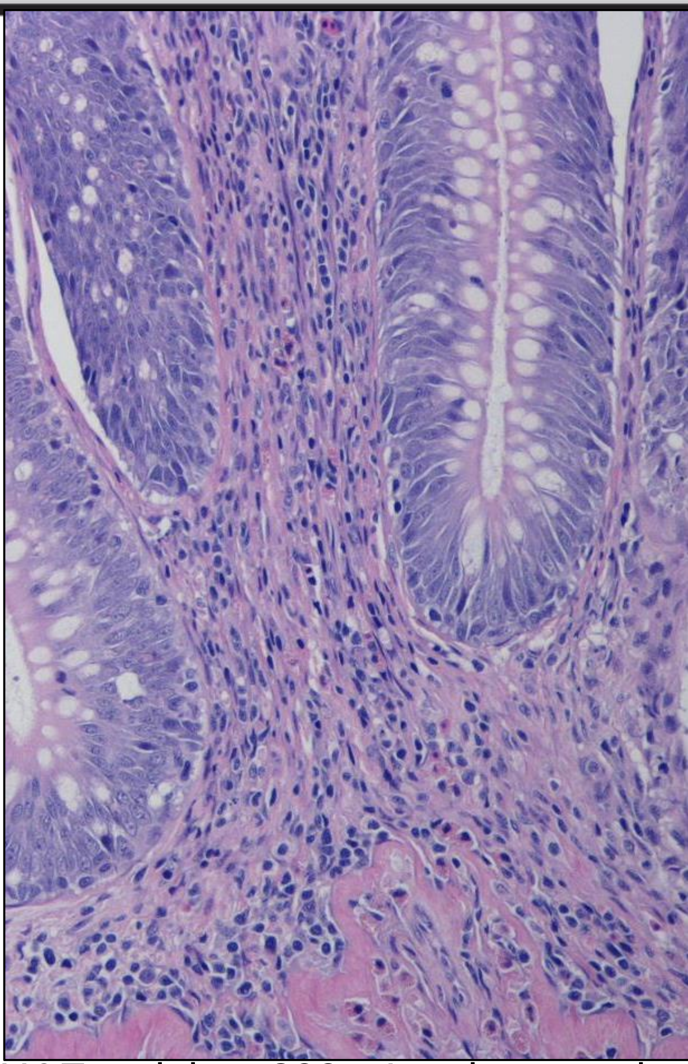
Side by side, grade 2 and grade 4

Things to note on grade 4 (right) include

- expansion of lamina propria (both between crypts as well as below the crypts)
- increased inflammation
- loss of SNV in epithelial cells
- increased Goblet cells in epithelium as compared to slide on the left

H&E staining, 200x, Lamina propria grade 1, TIC grade 2



H&E staining, 200x, Lamina propria grade 5; TIC grade 4

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What is the role of the gut microbiome?

Metchnikoff proposed the beneficial effects of intake of Lactobacilli over 100 years ago to improve digestion of milk and cheese

People who ate yogurt were consuming live Lactobacillis species

This led to development of probiotics, live bacteria as a healthy food supplement

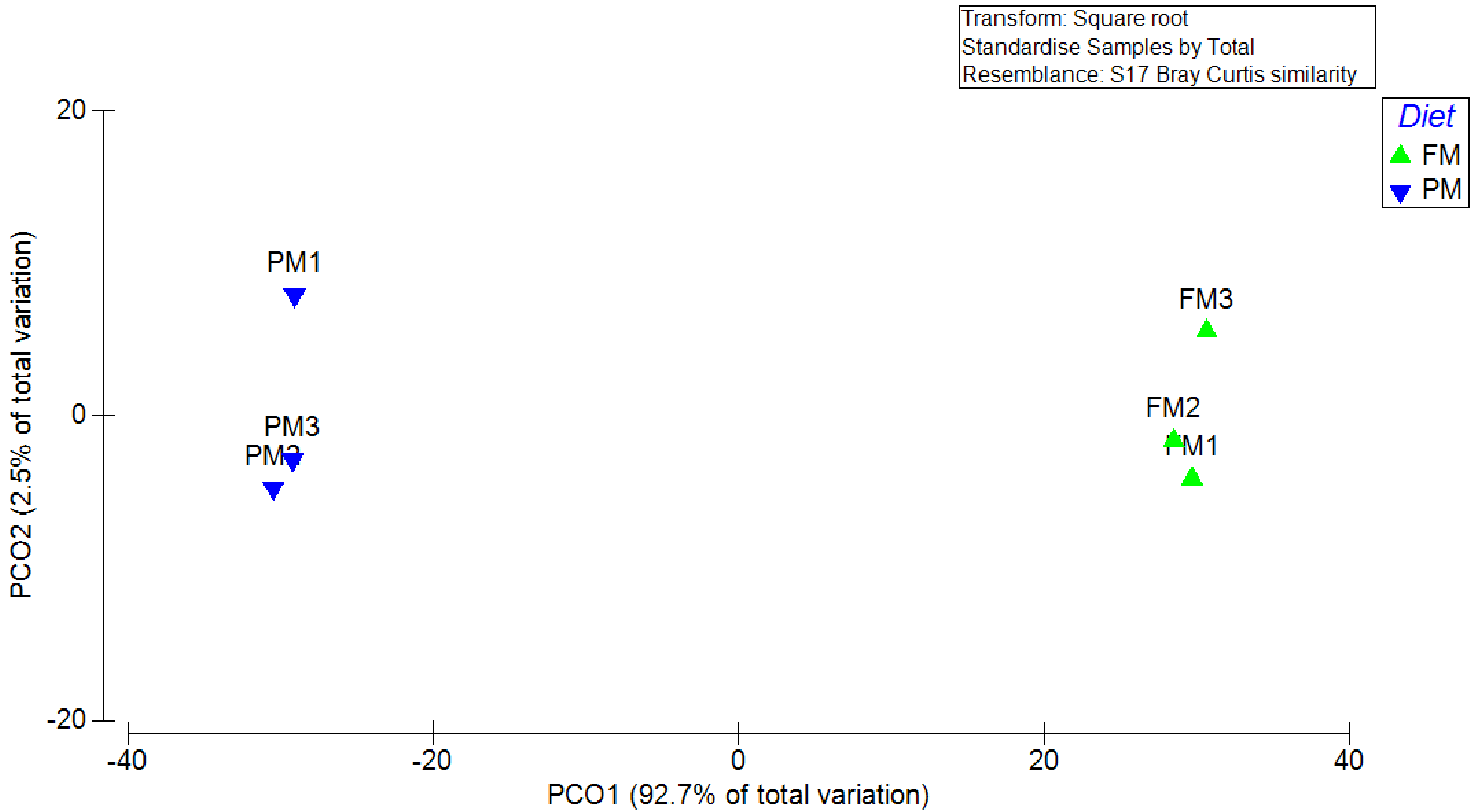
Metchnikoff understood that Lactobacilli require the necessary ‘prebiotic’ (lactose) from dairy products to flourish in the gut

For probiotics to be effective in animal or fish feeds, the proper ‘prebiotic’ must be present to provide food for the probiotic bacteria

Microbiome is changed by aquaculture

- In wild fish, natural food renews or maintains the microbiome
- In aquaculture, we provide artificial diets
  - They differ significantly in microbial population
  - They contain different “food” for the microbiome
    - Fiber, carbohydrates, other material are prebiotics
    - Their presence in feeds changes the microbial community
  - Antibiotics and other feed additives change the intestinal environment, altering the microbiome and affecting fish performance

Differences in feed microbiota



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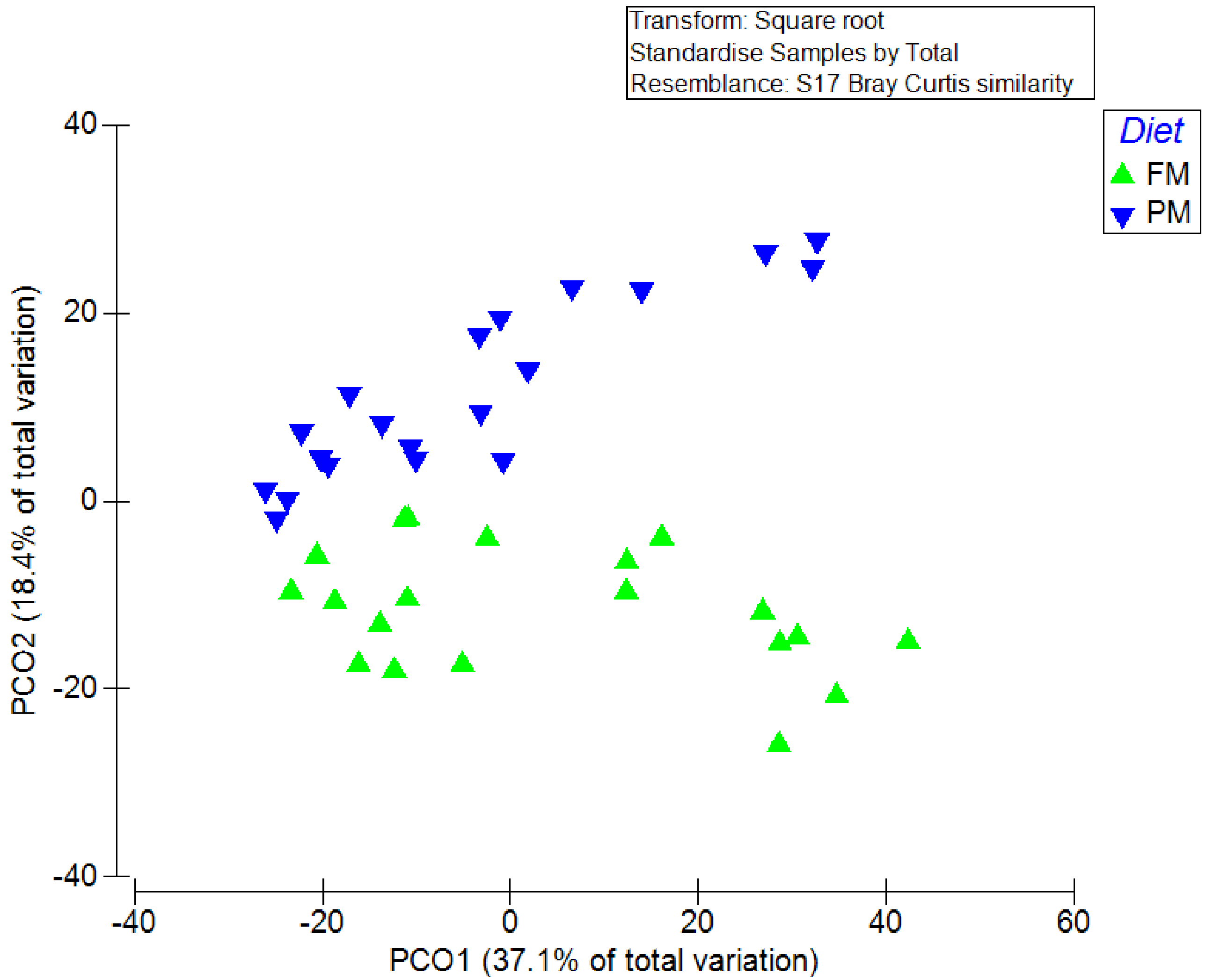
Microbiota of rainbow trout fed different diets



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Current status of fishmeal use

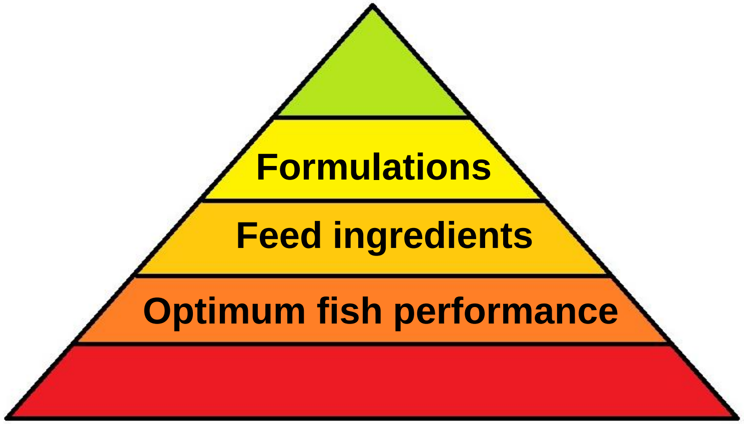
- Rainbow trout and salmon grow-out feeds contain <10% fishmeal
- Marine fish are stuck at >20% fishmeal
  - Diversity of species w/o much domestication
  - Insufficient data on nutrition requirements
    - Companies apply nutritional knowledge of salmon to marine fish, at least in Europe
    - Lowering fishmeal increased FCR from 1.45 to 2.0 since 2007
    - Another result is an increase in losses to disease
  - Lack of a holistic approach to fish nutrition and health
    - Companies apply nutritional knowledge of salmon to marine fish
    - Culture methods and lack of biosecurity in open-ocean pens

Can we eliminate fishmeal in salmon/trout feeds?

- **Easy if we include land animal proteins in formulations**
  - Poultry byproduct meal
  - Blood meal
  - Feather meal
- **Possible even without animal proteins**
  - Need to balance digestible amino acid content
  - Must supplement with minerals and amino acids
  - Most effective in grower feeds, not in feeds for fry or fingerlings
- **However, we face some unknowns**
  - Effects on physiology and immune function
  - Effects on FCRs and waste production that lowers water quality

Situation with salmon and trout today

- Low FM feeds are widely used
- Selective breeding of trout for high performance on all plant-protein feeds has been successful
  - 16 year, 8 generation effort at my institution
- Simultaneous efforts have been made to improve plant protein feeds
  - Efforts have followed the pyramid
    - Refining nutrient requirement levels
    - Identifying supplemental nutrients
    - Measuring nutrient availability
    - Testing feed formulations



Challenge for fish nutrition and physiology

- **Use gene expression information to identify key areas of gene regulation**
- **Integrate findings from cellular regulation with physiological data**
  - Digestion/absorption rates of proteins
- **Move to organism level**
  - Feed composition
  - Early life history (epigenetics)
  - Supplements to increase survival and ability to resist pathogens

Our Future – marine fish farming

Top seafoods consumed in the USA (lbs/person)

2002	2007	2012	2017
Shrimp 3.8	Shrimp 4.1	Shrimp 4.3	Shrimp 4.1
Tuna 3.2	Tuna 2.7	Tuna 2.4	Tuna 2.1
Salmon 2.1	Salmon 2.4	Salmon 2.8	Salmon 2.2
Pollock 1.5	Pollock 1.4	Pollock 1.3	Pollock 1.0
Catfish 1.1	Catfish 0.9	Catfish 0.8	Catfish 0.5
Cod 0.6	Cod 0.5	Cod 0.6	Cod 0.7
Crab 0.4	Crab 0.7	Crab 0.7	Crab 0.7
Tilapia 0.4	Tilapia 1.1	Tilapia 1.2	Tilapia 1.2
Asian catfish (0)	Asian catfish 0.2	Asian catfish 0.5	Asian catfish 0.9
Total per capita consumption	**15.7**	**14.4**	**15.0**

Farmed species in red

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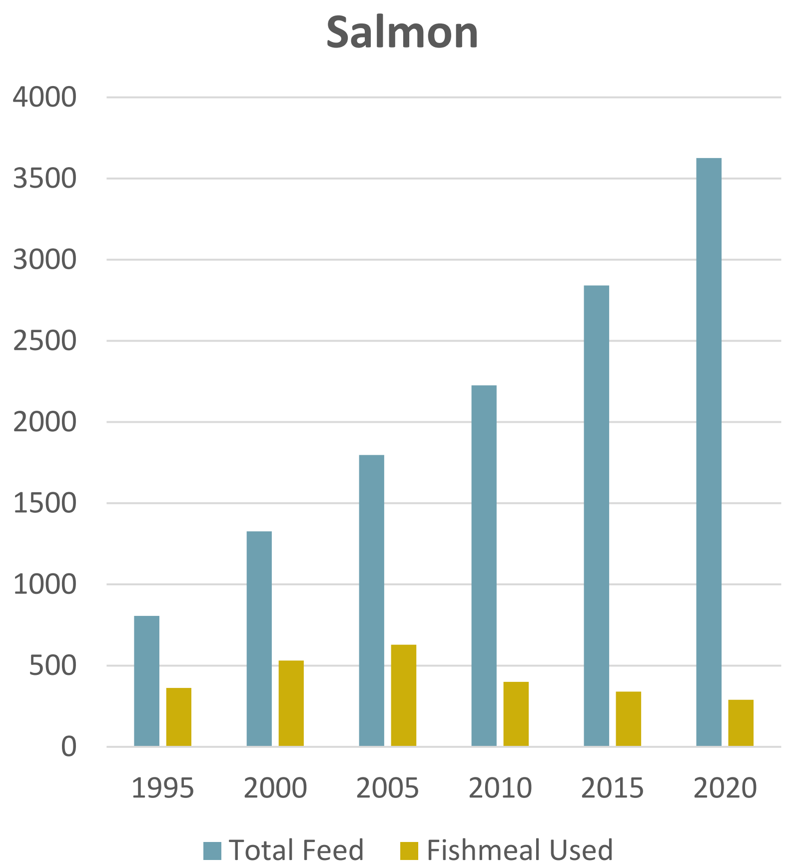
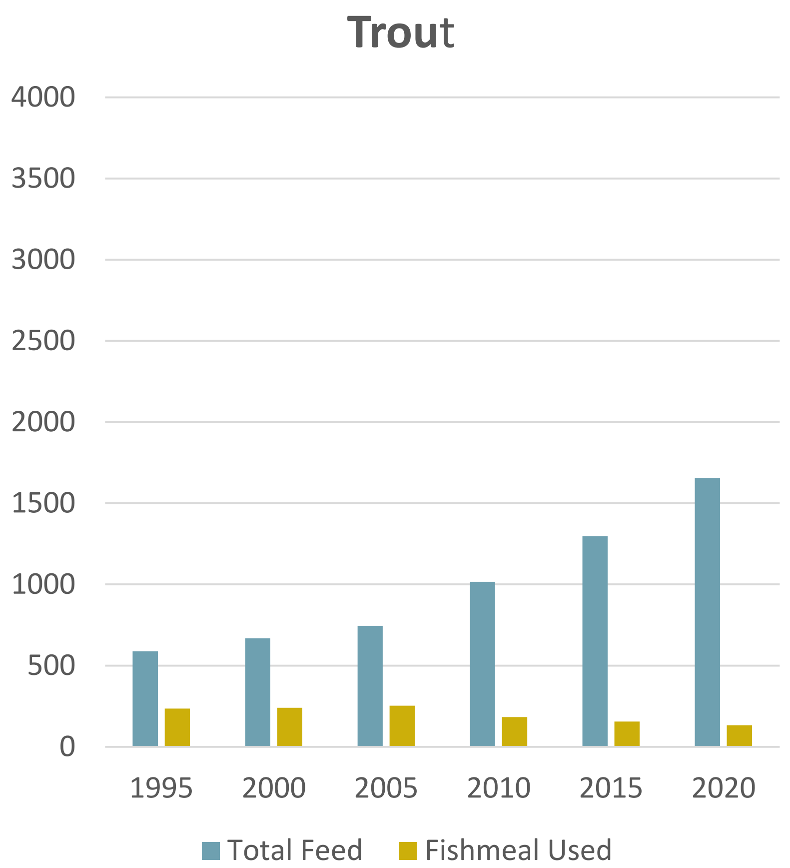
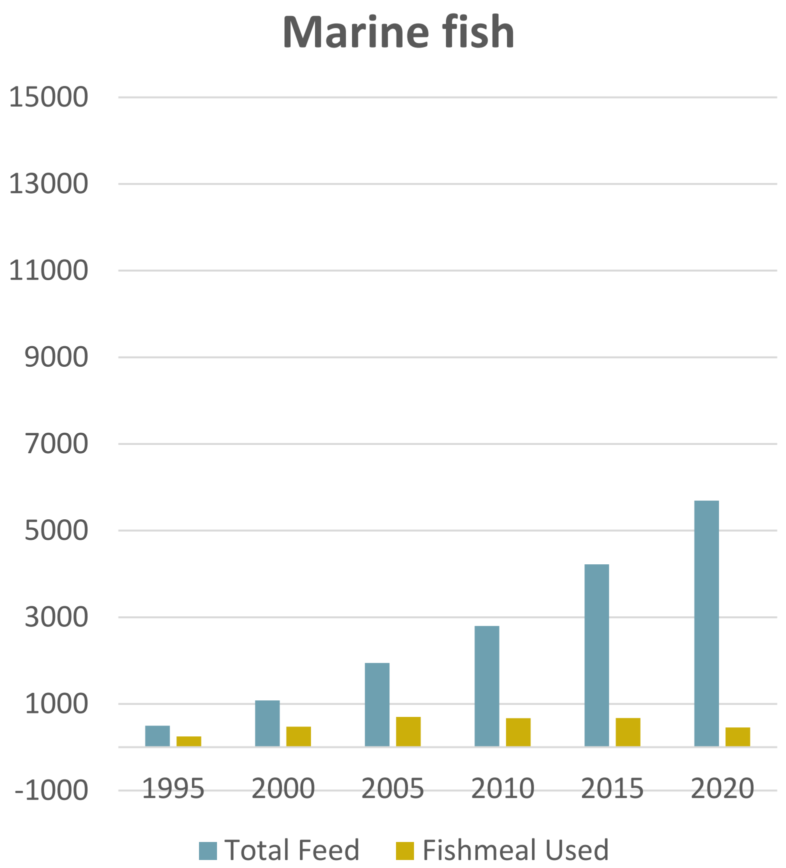
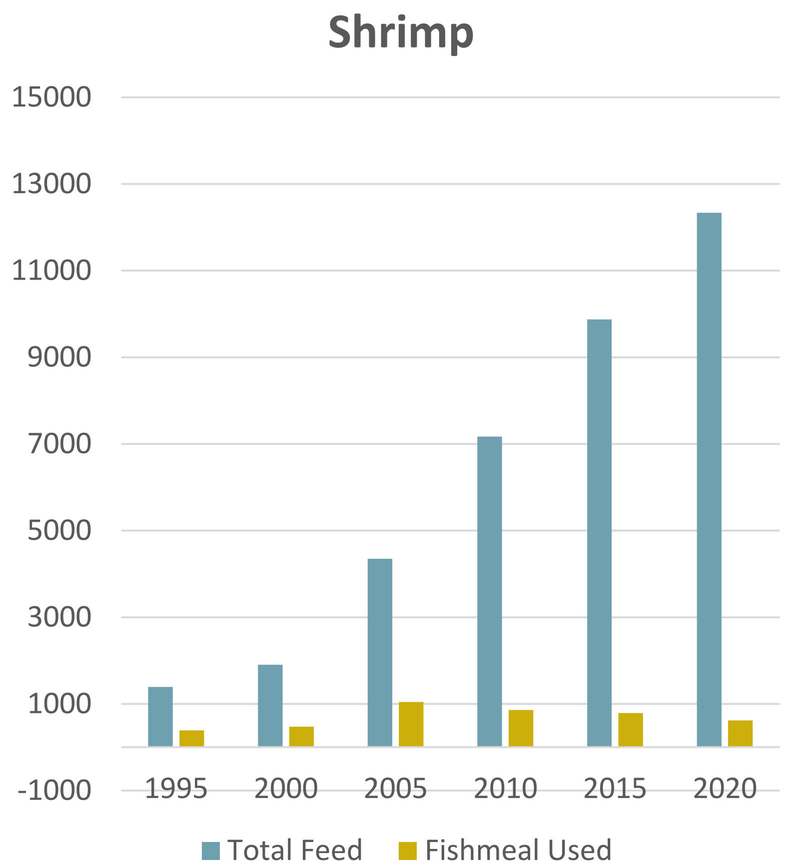
Total feed production and fishmeal use (000 mt)





Total feed production and fishmeal use (000 mt)





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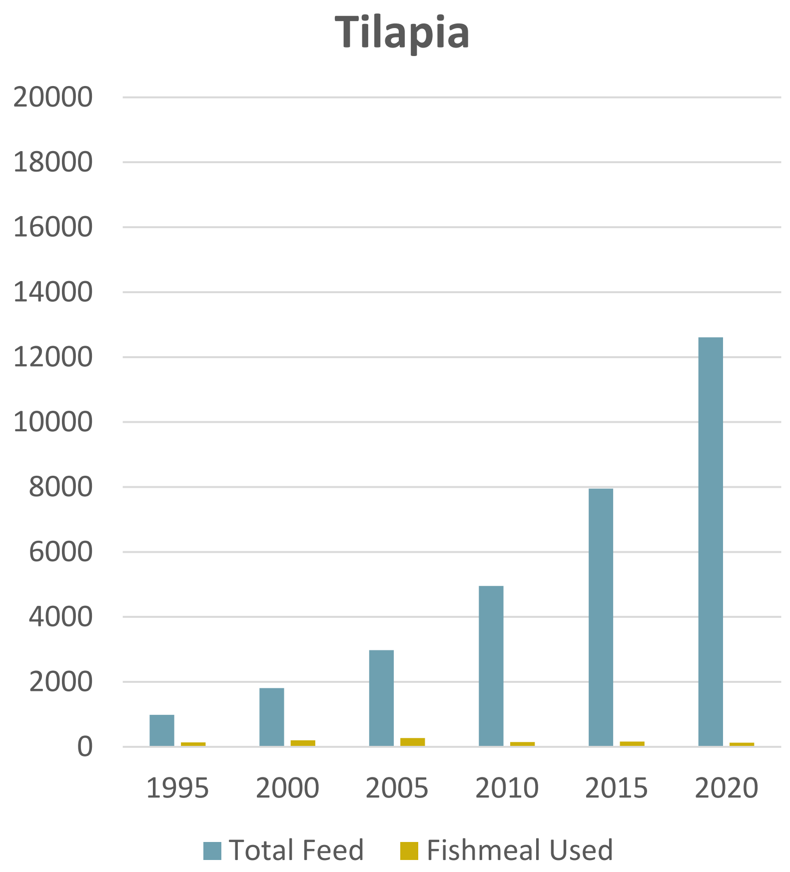
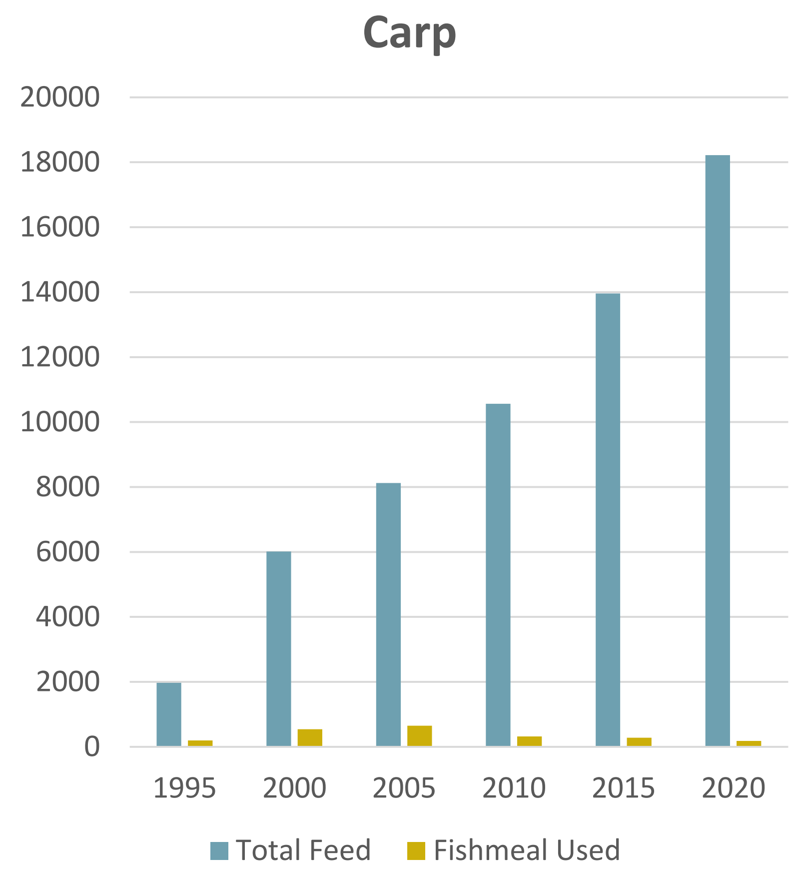




Soy and corn product comparison

	Soybean meal	Fermented soy	Enzyme-treated soy	Soy protein concentrate	Corn gluten meal	Corn protein concentrate
Protein (%)	48.5	55.6	61.5	63.4	63	76.2
Fat (%)	0.9	2.4	2	0.5	2.2	4.5
Lysine (%)	3.2	3.2	4.3	3.9	1.1	1.1
Methionine (%)	0.7	0.7	0.8	0.8	1.9	1.7
Price ($/ton)	$320	$650	$550	$900	$550	$700
Price/ton protein	$660	$1169	$894	$1420	$873	$918

Bacterial and insect product comparison

	BioProtein	Insect meal	Soy protein concentrate	Corn protein concentrate	Fishmeal
Protein (%)	61.3	40	65.9	76.2	65.4
Fat (%)	1.9	36	0.6	4.5	7.6
Lysine (%)	2.75	1.9	3.94	1.1	5.1
Methionine ($)	0.76	0.76	0.8	1.7	1.96
Price	?	?	$700	$700	$1450
Price/unit protein			$1420	$873	$2217

Characterizing the microbiome

For over 100 years, the only way to identify bacteria was to grow them in the lab

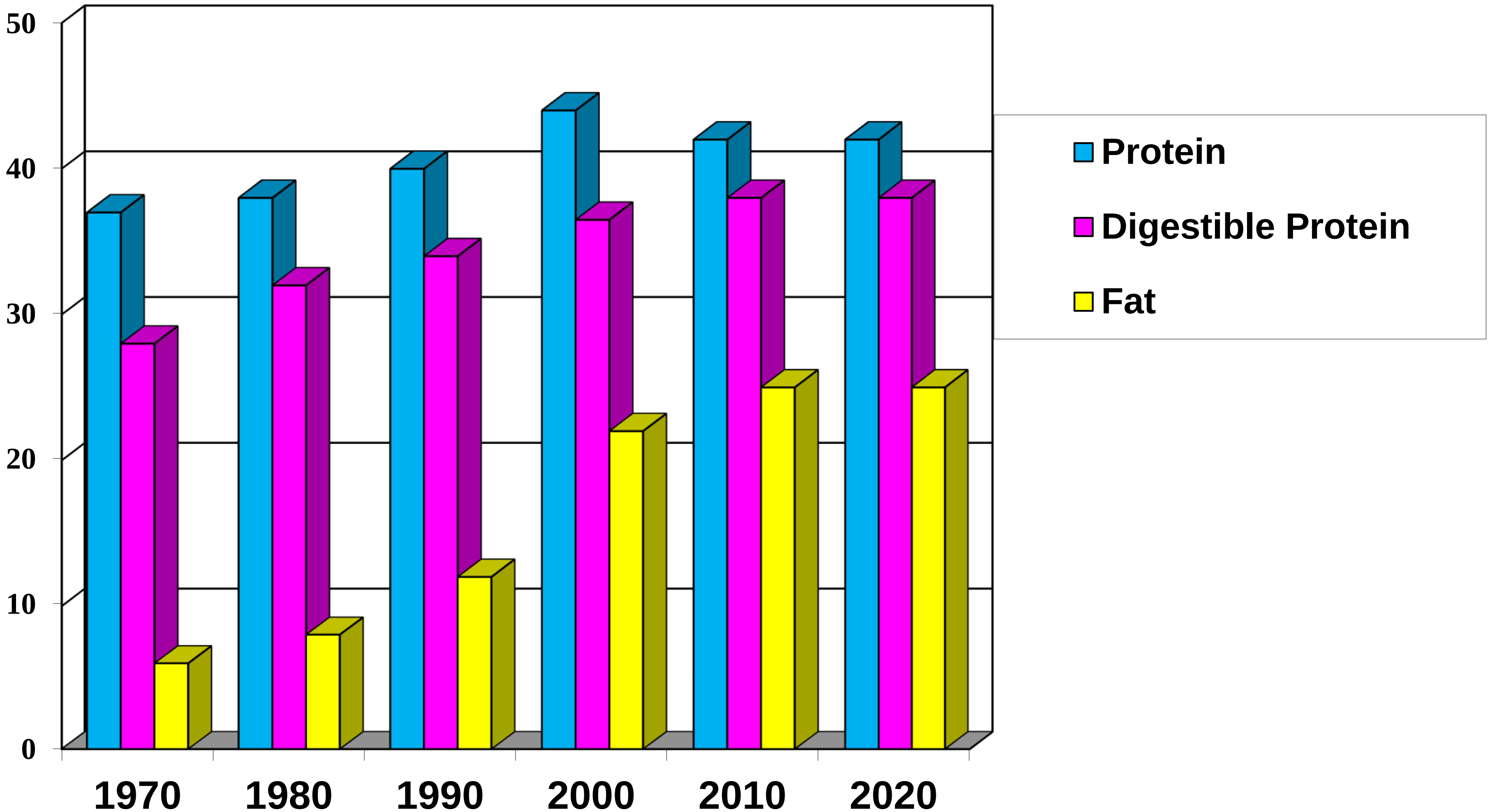
Characterizing the microbiome

- Researchers assumed that bacteria that were cultured were the complete population, but….
  - Not all bacteria can be grown in petri dishes
- Now researchers are using sequencing to identify bacteria
  - Sequencing identifies ALL microoganisms in the gut
  - Anaerobic bacteria greatly outnumber aerobic species in the gut
  - Some species produce antimicrobial compounds, some promote tight intestinal cell junctions, but others produce toxins that cause inflammation and infection

Recent trends in salmon and trout feeds

- **Since 1990s, lipid levels and digestible protein levels have increased**
- **Since 2007, fishmeal has dropped from >40% to 10-15% in salmon,trout and shrimp feeds**
- **Since 2005, >50% of fish oil has been replaced with plant oil (rapeseed, recovered poultry fat)**
- **Higher use of supplemental amino acids**

Changes in protein and fat levels in trout feeds



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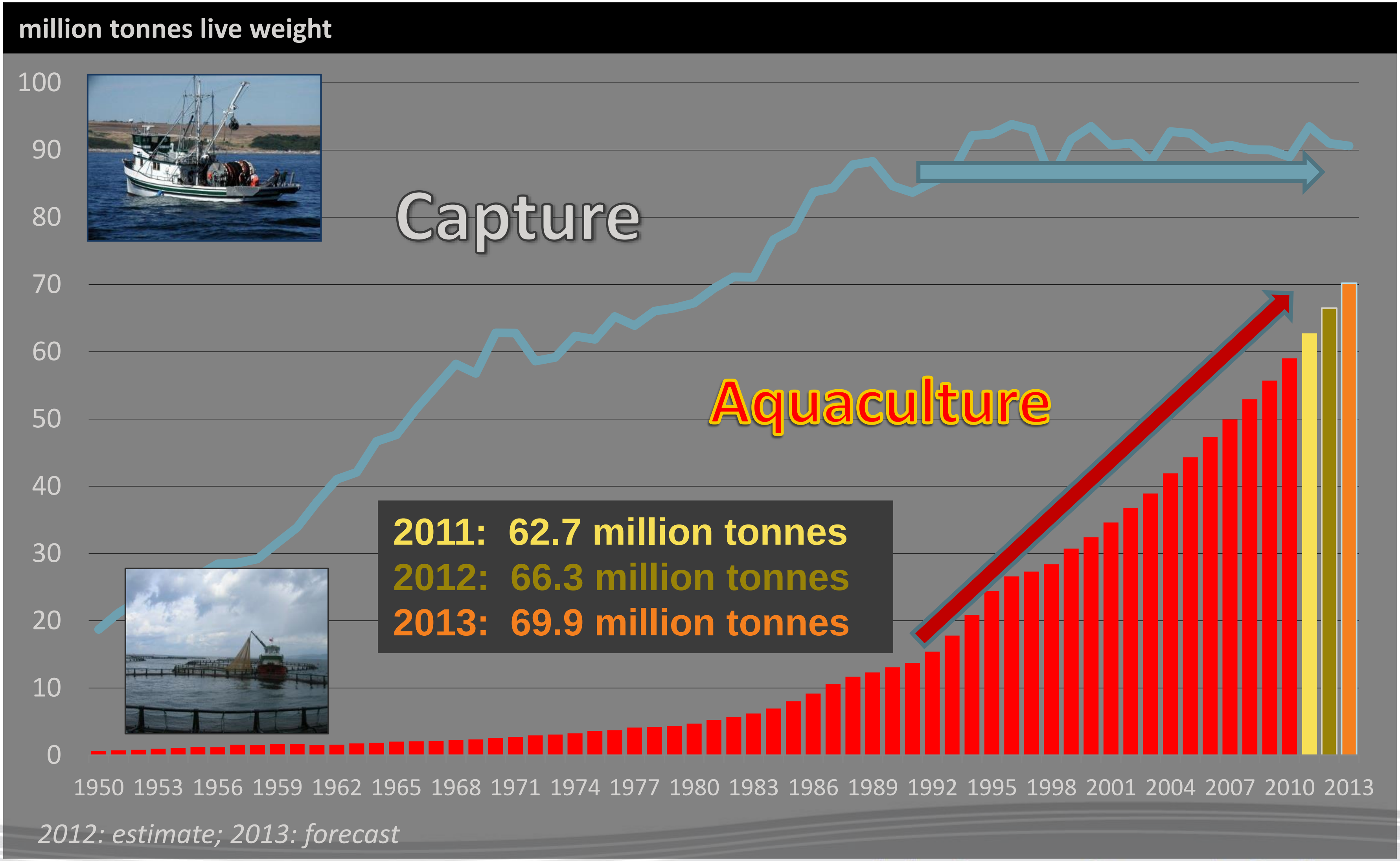
What has enabled these changes?

- Knowledge of nutrient requirements of trout and salmon, especially for amino acids
- Knowledge of protein and amino acid digestibility of ingredients
- Knowledge of effects of plant protein anti-nutrients and how to overcome or limit their effects

Why less positive results with marine fish?

- Incomplete knowledge of nutrient requirements
  - Response is to over-fortify feeds with micronutrients
    - This creates imbalances that modify metabolism
- Marine fish are less domesticated

Seafood Production



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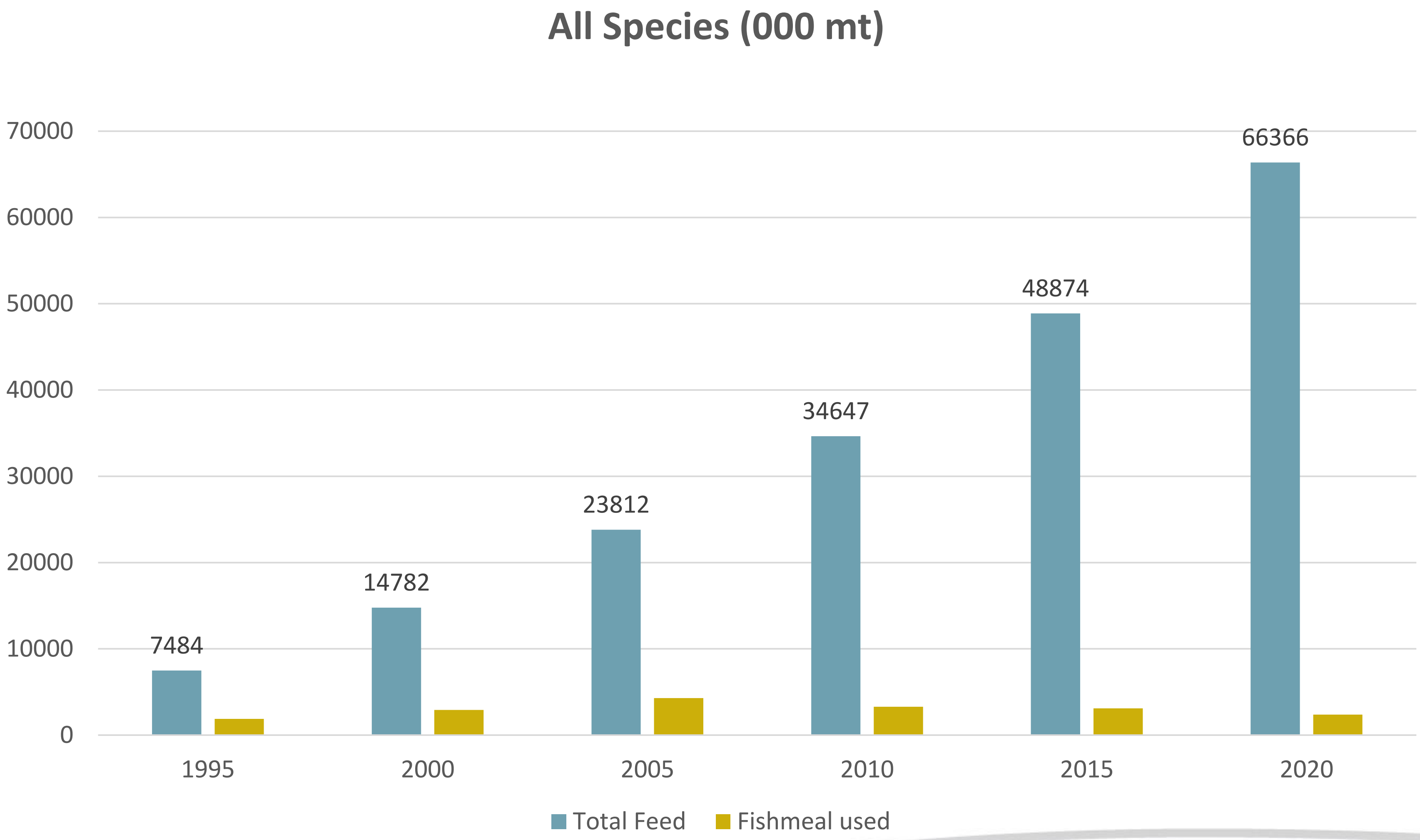
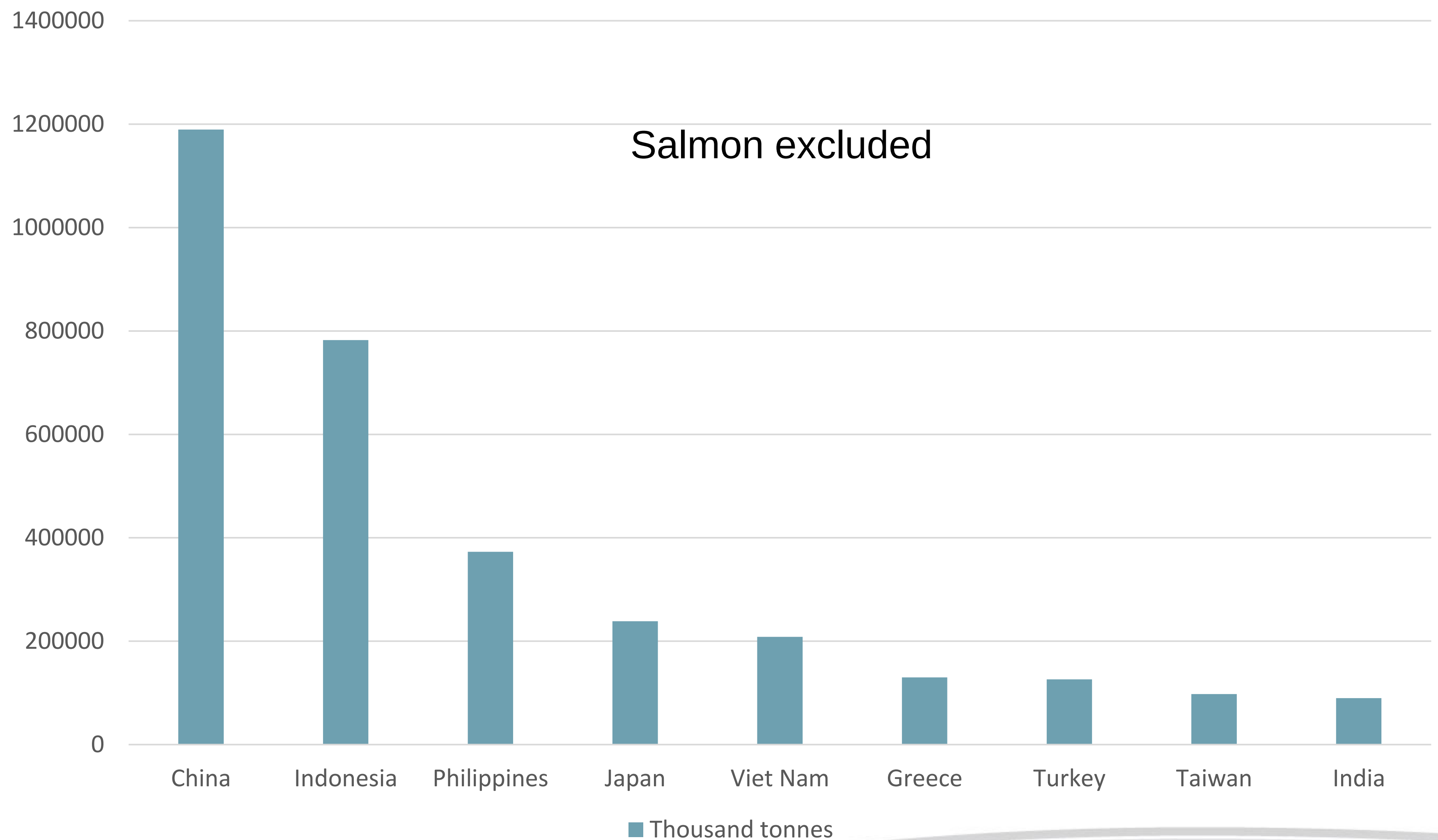
Fish feed production and fishmeal use



Top 10 producers (mt) of farmed marine fish



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Marine aquaculture production must increase

- Seafood demand will substantially increase due to population growth and rising incomes
- Marine aquaculture faces tough challenges
  - Broodstock and larvae sourcing (wild or captive?)
  - Feeds for farmed marine species
  - Health management (prevention, treatment
  - Water quality and environmental issues
- Can marine aquaculture simply adopt technology used to farm established farmed fish species, like salmon?
  - Reproduction, larval rearing, vaccines, advanced feeds

Grand challenge – sustainable fish feeds

- Annual global production of fishmeal and fish oil is insufficient to support current feed formulations
- Need to develop low fishmeal feeds for marine fish
  - Replace portion with alternative ingredients
  - Make feeds more efficient and less polluting
- Improvements in feeds can only take the industry so far
  - Must also improve farmed fish through domestication and selective breeding
  - Feed and fish improvement go hand-in-hand

Replacing fishmeal

- Plant protein concentrates (soy, wheat, corn) are top alternatives
  - Abundant & competitively priced compared to fishmeal protein
  - Favorable amino acid profile except for methionine (soy) and lysine (corn)
- Soy, wheat and corn products are primary ingredients in swine and poultry feeds
  - These animals are omnivores, so similar to catfish or tilapia, not marine fish
- Replacing fishmeal with plant proteins in fish feeds is challenging
  - Fishmeal is a complex material containing essential nutrients (amino acids, fatty acids, minerals and vitamins), biologically active compounds and high energy
  - Plant protein are made from seeds and seeds play defense
    - High in non-soluble CHO, anti-nutrients, indigestible P, non-tissue protein

Terrestrial vs aquatic food webs

- **Terrestrial life is based on plants converting sunlight and CO^2 into seeds, grasses, tubers, nuts and berries**
- **Seed by-products are the main ingredients in animal feeds**
  - **Soy and corn protein from residue after oil extraction**
  - **Wheat gluten from material remaining after flour removal**
- **Marine algae are primary producers in aquatic food webs**
  - **First level of food web is comprised of algae consumers**
  - **Every level above is comprised of animals consuming other animals**
- **Marine fish of interest are all carnivores, except for rabbitfish**
- **This reality complicates use of many plant-based ingredients in fish feeds, especially marine fish feeds**

Fish feed formulations have changed

- **Over the past decade, fishmeal levels in feeds have decreased by ~50%**
  - FM price doubled after 2006-2007, so change driven by in part by economics
  - Fishmeal protein has been replaced by plant and animal proteins
- **Outcomes differ among species groups**
  - Salmon and trout growth and feed efficiency unchanged
  - Marine species have experienced diminished productivity and various pathologies
    - Growth is slower
    - Feed conversion ratios higher (industry averaged 1.45 before 2007, now >2.0)
    - Mortalities up by 10-20%
  - These changes have increased cost of production significantly

Why the different outcomes among these species?

- Domestication
  - Marine fish are essential wild fish
    - For many species, broodstock are captured wild fish
    - For others, life cycle is closed but only recently
    - Some species are 4-5 years old before maturing
  - Salmon and trout have been farmed for many generations
- Selective breeding for growth
  - Active efforts with Atlantic salmon in Norway and Scotland
  - With trout, similar effort but accelerated since 2000
  - Marine fish – no serious effort
    - Life cycle must be closed to employ selective breeding schemes
    - Selection is futher complicated by reproductive behavior
      - » Mass spawning in tanks vs external fertilization with salmon/trout
      - » Must be able to do single-parent crosses and establish pedigree lines

Similar situation to trout and catfish in the 1970s

- **An El Nino event in the early 1970s resulted in a global shortage of fishmeal**
  - In the US, fishmeal levels in trout and catfish feeds were greatly reduced
  - Things went to hell in a handbasket – huge losses
  - The problem was lack of knowledge needed to formulate nutritionally-complete, balanced feeds
- **In the US, researchers embarked on a well-funded, national effort to estimate nutritional requirements of trout and catfish**
  - The effort included the first 3 tiers on Hardy's 'Hierarchy of Feeds'
    - Nutritional requirements, nutritional needs and feed ingredient knowledge
  - As a result, trout and catfish got to level 4 – successful feed formulation

Example of challenges – taurine and marine fish

- Taurine is a constituent of animal tissues and therefore present in fishmeal and land animal protein ingredients
  - Until recently, fish feeds contained relatively high amounts of fishmeal and therefore sufficient levels of taurine
  - Fish feeds now contain much lower amounts of fishmeal and trend is to reduce it further, lowering dietary taurine levels
- Taurine is not present in plants or seeds
- Taurine is a constituent of bile salts
- Soy proteins bind with bile acids in the distal intestine
  - This reduces entero-hepatic recycling of taurine and cholesterol
  - This increases amount of taurine required in feeds for optimum growth and health, especially for marine fish

Taurine story in marine fish

- Prior to late 1980s, no evidence of taurine requirement
- Collapse of Japanese sardine fishery caused yellowtail aquaculture industry to switch to high soy feeds
- Resulted in a new condition called 'green liver syndrome'
  - Found to be accumulation of bile pigments in liver
  - Bile acid synthesis was blocked due to lack of taurine
  - Supplementing feeds with taurine prevented the condition
- Story still evolving as evidence suggests that a fraction of soy binds bile acids, complicating establishment of a requirement
  - Called 'soystatin' and is a cholesterol-lowering drug, like cholestyramine

Hardy's predictions

- More robust larvae and fry as a result of *improved genetic selection and better starter feeds*
- Improved 'balanced' feeds for post-juvenile marine fish (specifically formulated for marine fish)
  - FCR's will fall by 25% within a few years
  - Fishmeal levels will decrease by 35-50%
  - Functional feeds will improve fish health and reduce losses to parasites and pathogens (viral and bacterial)
- The fish oil problem will be overcome
  - Marine algae products will become economically feasible