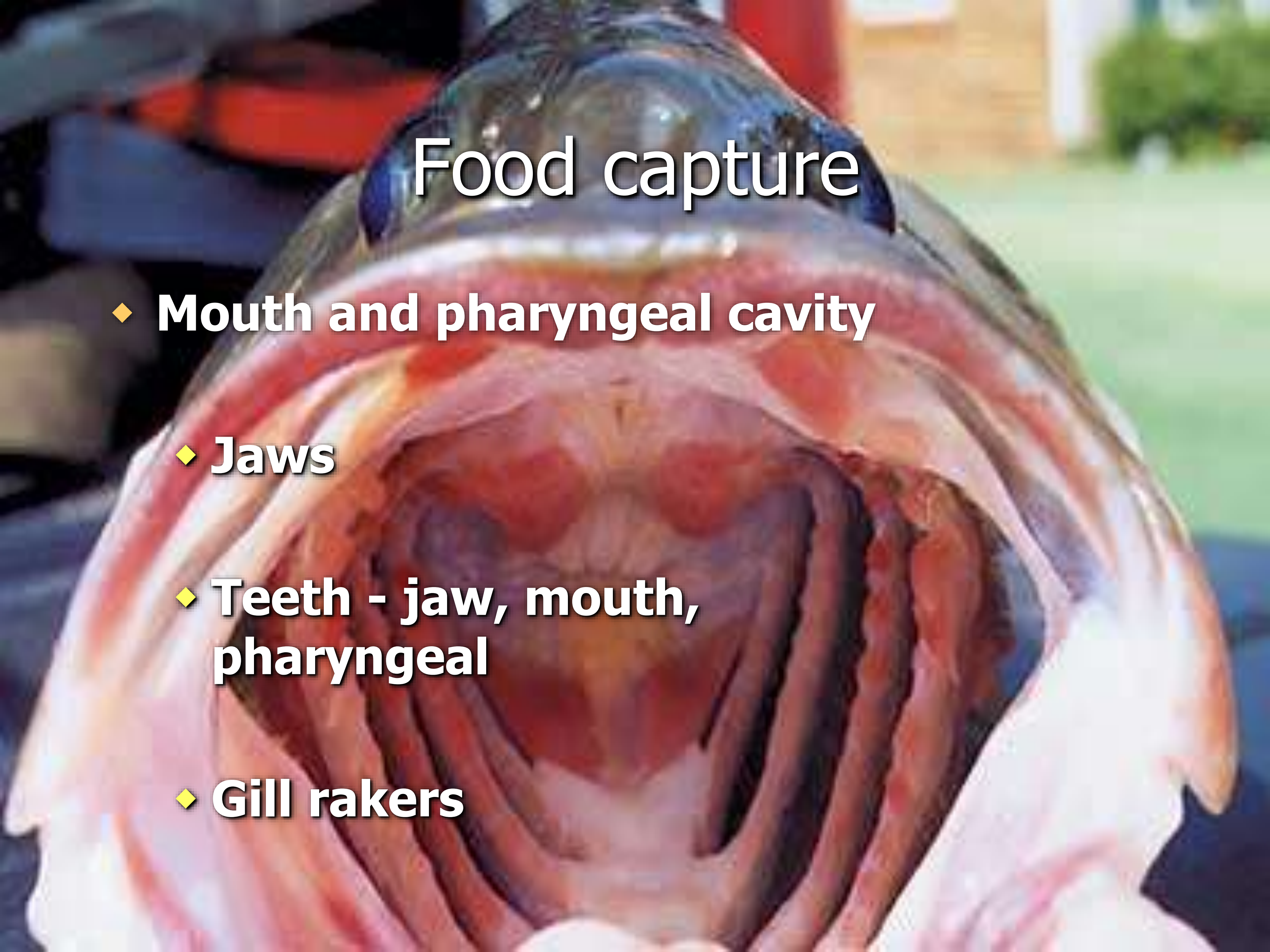
Feeding & Food Processing

1. Structure (review)
2. Function (behavior, physiology)
3. Nutritional needs
4. Digestive efficiency



Food capture

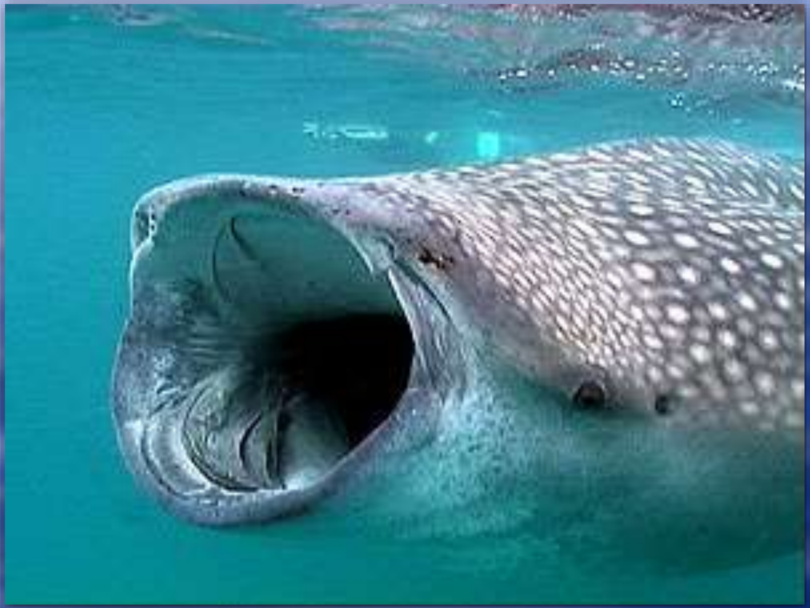
- **Mouth and pharyngeal cavity**
  - **Jaws**
  - **Teeth - jaw, mouth, pharyngeal**
  - **Gill rakers**

Fish Feeding - function

- Herbivores
  - < 5% of all bony fishes, no cartilaginous fishes
    - browsers - selective - eat only the plant
    - grazers - less selective - include sediments
- Detritivores
  - 5 - 10% of all species
  - feed on decomposing organic matter

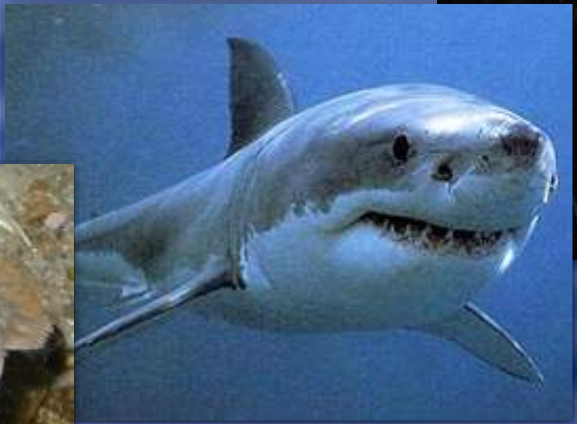
Fish Feeding – function

- Carnivores
  - zooplanktivores
    - suction feeding
    - ram feeding
  - benthic invertebrate feeders
    - graspers
    - pickers
    - sorters
    - crushers



Fish Feeding – function

- More Carnivores
  - fish feeders
    - active pursuit
    - stalking
    - ambushing
    - luring



Fish feeding behavior

- Fish feeding behavior integrates **morphology** with **perception** to obtain food:
  - Search --> Detection --> Pursuit --> Capture --> Ingestion

Feeding behavior

- **Fish show versatility in prey choice and ingestion**
- **Behavior tightly linked to morphology (co-evolution)**

Fish feeding behavior

- **Behavior tends to be optimizing when choices are available**
  - **Optimal = maximize benefit:cost ratio**
  - **More for less!**
  - **Select the prey that yields the greatest energetic or nutrient "return" on the energy invested in search, pursuit, capture, and ingestion**

Fish digestive physiology

- After ingestion of food, gut is responsible for:
  - **Digestion** - breaking down food into small, simple molecules
    - involves use of acids, enzymes
  - **Absorption** - taking molecules into blood
    - diffusion into mucosal cells
    - phagocytosis/pinocytosis by mucosal cells
    - active transport via carrier molecules

Digestive Apparati

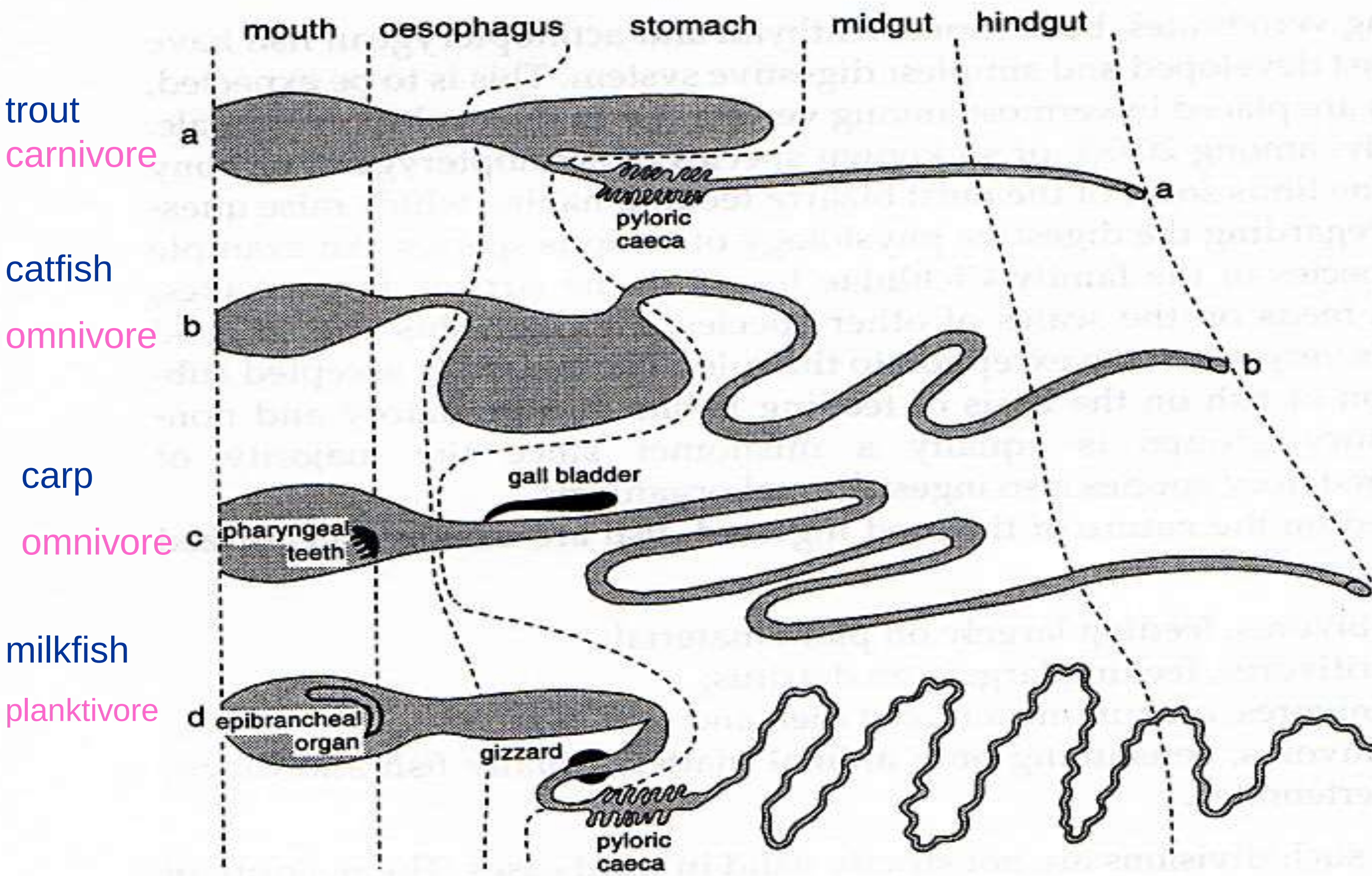


Figure 4.1 The digestive systems of four fish described in the text, arrang order of increasing gut length. (a) Rainbow trout (carnivore). (b) Catfish (omnivore emphasizing animal sources of food). (c) Carp (omnivore, emphasizing plant sources of food). (d) Milkfish (microphagous planktivo (From Smith, 1980.)

Fish Digestion

- Two major groups: w/stomach, w/out
- w/out stomach: cyprinids (carps)
- w/stomach: cold-water salmonids, warm-water catfish, tilapia, eels, grouper
- note: all "pure" predators have a stomach and teeth
- **relative gut length (RGL):** gut:body length
- high RGL = species consuming detritus, algae (high proportion of indigestible matter)

Relative Gut Length

Species	Feeding	RGL
Labeo horie	Algae, detritus	15.5
Garra dembensis	Algae, inverts	4.5
Barbus sharpei	Plants	2.8-3.1
Chelethiops elongatus	Zooplankton	0.7
Chela bacaila	Carnivorous	0.9

Fish Digestive Morphology: Major Divisions

- Mouth
- Esophagus
- Pharynx
- Stomach
- Intestine
- Rectum
- Secretory glands (liver and pancreas)
- often difficult to distinguish

Gastrointestinal Tract

- Esophagus
- Stomach
  - large in carnivores, small in herbivores/omnivores
- Pyloric caeca
- Intestine
  - short in carnivores, long in herbivores-omnivores
- Anus - separate from urogenital pore

GI Tract- Secretory Glands

- **Liver**
  - **produces bile (lipolysis)**
  - **stores glycogen**
  - **stores lipids**
- **Pancreas**
  - **digestive enzymes**
    - **proteases - protein breakdown**
    - **amylases - starch breakdown**
    - **chitinases - chitin breakdown**
    - **lipases - lipid breakdown**

Digestive Anatomy: Mouth/Esophagus

- *Channel catfish:* large mouth/esophagus, capture prey, slightly predaceous, mouth has no teeth, no gizzard/cardiac sphincter
- *Common carp:* small mouth for bottom feeding, pharyngeal teeth, grinds food
- *Tilapia:* combination of bottom feeder, predator, efficient plankton feeder, uses gill rakers, pharyngeal mucous

Digestive Anatomy: Stomach

- *Channel catfish:* have true stomach that secretes HCl and pepsinogen (enzyme)
- *Common carp:* no stomach; however, "bulb" at anterior end of digestive tract, bile and pancreatic secretions empty into intestine posterior to cardiac sphincter, no secretion of gastrin (low pH)
- *Tilapia:* modified stomach, secretes HCl, well-defined pocket, pH varies w/digestal flow, has pyloric sphincter

Digestive Anatomy: Intestine

- *Channel catfish*: length less than whole body, no large/small version, slightly basic pH, digestive secretions, nutrient absorption, many folds for absorption
- *Common carp*: digestive tract is 3x whole body length, similar in activity to that of channel catfish
- *Tilapia*: tract is 6-8x that of body length, activities similar to that of other species

Digestive Anatomy: Liver and Pancreas

- Both organs produce digestive secretions
- Liver produces bile but is also the primary organ for synthesis, detoxification and storage of many nutrients
- Pancreas is primary source of digestive enzymes in most animals
- It also produces **zymogens** (precursors to enzymes)

Fish Digestive Physiology

- Digestion is accomplished in
  - Stomach
    - low pH - HCl, other acids (2.0 for some tilapia!)
    - proteolytic enzymes (mostly pepsin)

Digestive Processes: Stomach

- Catfish as an example - its digestive processes are similar to that of most monogastric animals

- Food enters stomach, neural and hormonal processes stimulate digestive secretions
- As stomach distends, parietal cells in lining secrete **gastrin**, assisting in digestion
- Gastrin converts the zymogen **pepsinogen** to **pepsin** (a major proteolytic enzyme)
- Some fish have **cirulein** instead of gastrin

Digestive Processes: Stomach

- Flow of **digesta** out of stomach is controlled by the pyloric sphincter
- **Pepsin** has pH optimum and lyses protein into small peptides for easier absorption
- Minerals are solubilized; however, no lipid or COH is modified
- Mixture of gastric juices, digesta, mucous is known as **chyme**

Fish Digestive Physiology

- Digestion is accomplished in
  - Stomach
  - Intestine
    - alkaline pH (7.0 - 9.0)
    - proteolytic enzymes - from pancreas & intestine
    - amylases (carbohydrate digestion) - from pancreas & intestine
    - lipases (lipid digestion) - from pancreas & liver (gall bladder, bile duct)

Digestive Processes: Intestine

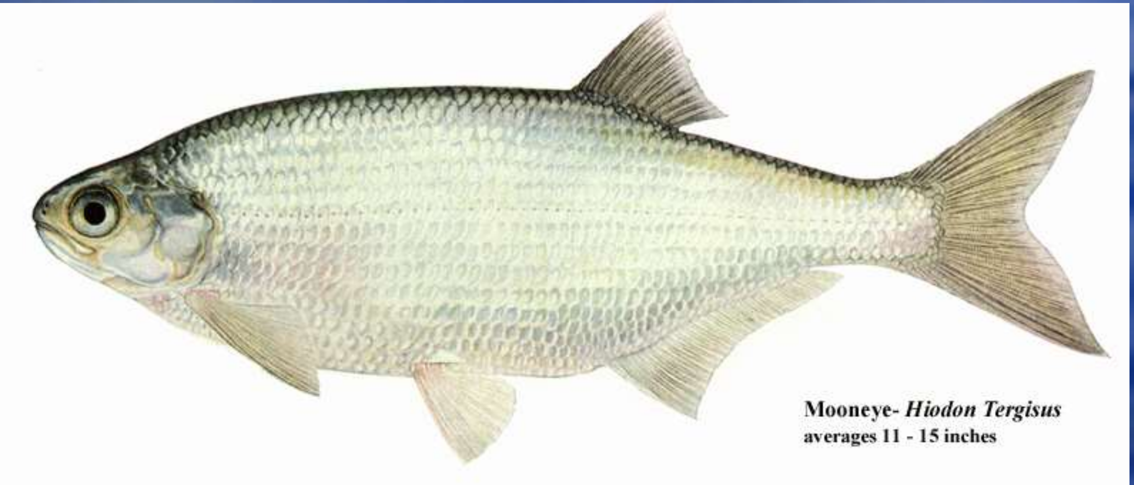
- **Chyme** entering the small intestine stimulates secretions from the pancreas and gall bladder (**bile**)
- Bile contains salts, cholesterol, phospholipids, pigments, etc.
- Pancreatic secretions include bicarbonates which buffer acidity of the chyme
- Zymogens for proteins, COH, lipids, chitin and nucleotides are secreted
- e.g., **enterokinase** (trypsinogen --> trypsin)
- Others: chymotrypsin, carboxypeptidase, aminopeptidase, chitinase

Digestive Processes: Intestine

- Digestion of carbohydrates is via **amylase**, which hydrolyzes starch
- Others: **nuclease, lipase**
- **Cellulase**: interesting in that it is not secreted by pancreas, but rather produced by gut bacteria
- Note: intestinal mucosa also secretes digestive enzymes

Fish digestive physiology

- Absorption is accomplished in
  - Intestine
    - diffusion into mucosal cells
    - phagocytosis/pinocytosis by mucosal cells
    - active transport via carrier molecules



Digestive processes: Absorption

- Most nutrient absorption occurs in the intestine
- Cross-section of the intestinal luma shows that it is highly convoluted, increasing surface area
- Absorption through membrane is either by **passive diffusion** (concentration gradient)
- Or by **active transport** (requires ATP)
- Or via **pinocytosis** (particle engulfed)
- Nutrients absorbed by passive diffusion include: electrolytes, monosaccharides, some vitamins, smaller amino acids

Digestive processes: absorption

- Proteins are absorbed primarily as amino acids, **dipeptides** or **tripeptides**
- triglycerides are absorbed as **micelles**
- COH's absorbed as **monosaccharides** (e.g., glucose, except for crustaceans)
- calcium and phosphorus are usually complexed together for absorption
- all nutrients, excluding some lipids, are absorbed from the intestine via the hepatic portal vein to the liver

Summary of Digestive Enzymes

Site/Type	Fluid/enzyme	Function/notes
Stomach	HCl	Reduces gut pH, pepsiongen
Gastric secretions	Zymogen, pepsinogen, HCl	Proteolysis
	Amylase	COH's
	Lipase	Lipids
	Esterase	Esters
	Chitinase	Chitin
Pancreas	HCO_3	Neutralizes HCl
	Proteases	Cleave peptide linkages
	Amylase	COH's
	Lipase	Lipids
	Chitinase	Chitin
Liver/bile	Bile salts, cholestrol	Increase pH, emulsify lipids
Intestine	Aminopeptidases	Split nucleosides
	Lecithinase	Phospholipids to glycerol + fatty acids

Fish Nutritional Needs

- **High protein diet:**
  - **Carnivores - 40 - 55% protein needed**
  - **Omnivores - 28 - 35% protein needed**

  - **Birds & mammals - 12 - 25% protein needed**
  - **10 essential amino acids (PVT. TIM HALL)**

Phenylalanine, Valine, Tryptophan, Threonine, Isoleucine, Methionine, Histidine, Arginine, Leucine, Lysine.

Fish Nutritional Needs

- **High protein diet**
- **Why so high?**
  - **Proteins needed for growth of new tissue**
  - **Proteins moderately energy-dense (don’t need dense source - ectotherms, low gravity)**
  - **Few side-effects - ease of NH_4^+ excretion**

Protein

Because protein is the most expensive part of fish feed, it is important to accurately determine the protein requirements for each species and size of cultured fish. Proteins are formed by linkages of individual amino acids. Although over 200 amino acids occur in nature, only about 20 amino acids are common. Of these, 10 are essential (indispensable) amino acids that cannot be synthesized by fish. The 10 essential amino acids that must be supplied by the diet are: methionine, arginine, threonine, tryptophan, histidine, isoleucine, lysine, leucine, valine and phenylalanine. Of these, lysine and methionine are often the first limiting amino acids. Fish feeds prepared with plant (soybean meal) protein typically are low in methionine; therefore, extra methionine must be added to soybean-meal based diets in order to promote optimal growth and health. It is important to know and match the protein requirements and the amino acid requirements of each fish species reared.

Protein levels in aquaculture feeds generally average 18-20% for marine shrimp, 28-32% for catfish, 32-38% for tilapia, 38-42% for hybrid striped bass. Protein requirements usually are lower for herbivorous fish (plant eating) and omnivorous fish (plant-animal eaters) than they are for carnivorous (flesh-eating) fish, and are higher for fish reared in high density (recirculating aquaculture) than low density (pond aquaculture) systems.

Protein requirements generally are higher for smaller fish. As fish grow larger, their protein requirements usually decrease. Protein requirements also vary with rearing environment, water temperature and water quality, as well as the genetic composition and feeding rates of the fish. Protein is used for fish growth if adequate levels of fats and carbohydrates are present in the diet. If not, protein may be used for energy and life support rather than growth.

Proteins are composed of carbon (50%), nitrogen (16%), oxygen (21.5%), and hydrogen (6.5%). Fish are capable of using a high protein diet, but as much as 65% of the protein may be lost to the environment. Most nitrogen is excreted as ammonia (NH_3) by the gills of fish, and only 10% is lost as solid wastes. Accelerated eutrophication (nutrient enrichment) of surface waters due to excess nitrogen from fish farm effluents is a major water quality concern of fish farmers. Effective feeding and waste management practices are essential to protect downstream water quality.

Lipids (fats)

Lipids (fats) are high-energy nutrients that can be utilized to partially spare (substitute for) protein in aquaculture feeds. Lipids supply about twice the energy as proteins and carbohydrates. Lipids typically comprise about 15% of fish diets, supply essential fatty acids (EFA) and serve as transporters for fat-soluble vitamins.

A recent trend in fish feeds is to use higher levels of lipids in the diet. Although increasing dietary lipids can help reduce the high costs of diets by partially sparing protein in the feed, problems such as excessive fat deposition in the liver can decrease the health and market quality of fish.

Simple lipids include fatty acids and triacylglycerols. Fish typically require fatty acids of the omega 3 and 6 (n-3 and n-6) families.

Fatty acids can be: a) saturated fatty acids (SFA, no double bonds), b) polyunsaturated fatty acids (PUFA, >2 double bonds), or c) highly unsaturated fatty acids (HUFA; > 4 double bonds).

Marine fish oils are naturally high (>30%) in omega 3 HUFA, and are excellent sources of lipids for the manufacture of fish diets. Lipids from these marine oils also can have beneficial effects on human cardiovascular health.

Marine fish typically require n-3 HUFA for optimal growth and health, usually in quantities ranging from 0.5-2.0% of dry diet. The two major EFA of this group are eicosapentaenoic acid (EPA: 20:5n-3) and docosahexaenoic acid (DHA:22:6n-3). Freshwater fish do not require the long chain HUFA, but often require an 18 carbon n-3 fatty acid, linolenic acid (18:3-n-3), in quantities ranging from 0.5 to 1.5% of dry diet. This fatty acid cannot be produced by freshwater fish and must be supplied in the diet. Many freshwater fish can take this fatty acid, and through enzyme systems elongate (add carbon atoms) to the hydrocarbon chain, and then further desaturate (add double bonds) to this longer hydrocarbon chain.

Through these enzyme systems, freshwater fish can manufacture the longer chain n-3 HUFA, EPA and DHA, which are necessary for other metabolic functions and as cellular membrane components. Marine fish typically do not possess these elongation and desaturation enzyme systems, and require long chain n-3 HUFA in their diets. Other fish species, such as tilapia, require fatty acids of the n-6 family, while still others, such as carp or eels, require a combination of n-3 and n-6 fatty acids

Carbohydrates

Carbohydrates (starches and sugars) are the most economical and inexpensive sources of energy for fish diets. Although not essential, carbohydrates are included in aquaculture diets to reduce feed costs and for their binding activity during feed manufacturing. Dietary starches are useful in the extrusion manufacture of floating feeds. Cooking starch during the extrusion process makes it more biologically available to fish.

In fish, carbohydrates are stored as glycogen that can be mobilized to satisfy energy demands. They are a major energy source for mammals, but are not used efficiently by fish. For example, mammals can extract about 4 kcal of energy from 1 gram of carbohydrate, whereas fish can only extract about 1.6 kcal from the same amount of carbohydrate. Up to about 20% of dietary carbohydrates can be used by fish.

Vitamins

Vitamins are organic compounds necessary in the diet for normal fish growth and health. They often are not synthesized by fish, and must be supplied in the diet.

The two groups of vitamins are water-soluble and fat-soluble.

Water-soluble vitamins include: the B vitamins, choline, inositol, folic acid, pantothenic acid , biotin and ascorbic acid (vitamin C). Of these, vitamin C probably is the most important because it is a powerful antioxidant and helps the immune system in fish.

The fat-soluble vitamins include A vitamins, retinols (responsible for vision); the D vitamins, cholecaciferols (bone integrity); E vitamins, the tocopherols (antioxidants); and K vitamins such as menadione (blood clotting, skin integrity). Of these, vitamin E receives the most attention for its important role as an antioxidant.

Deficiency of each vitamin has certain specific symptoms, but reduced growth is the most common symptom of any vitamin deficiency. Scoliosis (bent backbone symptom) and dark coloration may result from deficiencies of ascorbic acid and folic acid vitamins, respectively.

Minerals

Minerals are inorganic elements necessary in the diet for normal body functions. They can be divided into two groups (macro-minerals and micro-minerals) based on the quantity required in the diet and the amount present in fish. Common macro-minerals are sodium, chloride, potassium and phosphorous. These minerals regulate osmotic balance and aid in bone formation and integrity.

Micro-minerals (trace minerals) are required in small amounts as components in enzyme and hormone systems. Common trace minerals are copper, chromium, iodine, zinc and selenium. Fish can absorb many minerals directly from the water through their gills and skin, allowing them to compensate to some extent for mineral deficiencies in their diet.

Energy and Protein

Dietary nutrients are essential for the construction of living tissues. They also are a source of stored energy for fish digestion, absorption, growth, reproduction and the other life processes. The nutritional value of a dietary ingredient is in part dependant on its ability to supply energy. Physiological fuel values are used to calculate and balance available energy values in prepared diets. They typically average 4, 4, and 9 kcal/g for protein, carbohydrate and lipid, respectively.

To create an optimum diet, the ratio of protein to energy must be determined separately for each fish species. Excess energy relative to protein content in the diet may result in high lipid deposition. Because fish feed to meet their energy requirements, diets with excessive energy levels may result in decreased feed intake and reduced weight gain. Similarly, a diet with inadequate energy content can result in reduced weight gain because the fish cannot eat enough feed to satisfy their energy requirements for growth. Properly formulated prepared feeds have a well-balanced energy to protein ratio.

Nutritional efficiency in fishes

- Fish more efficient than other vertebrates:
  - Conversion factor = kg feed required to produce 1 kg growth in fish flesh
    - Fishes: 1.7 - 5.0
    - Birds & mammals: 5.0 - 15.0

Nutritional efficiency in fishes

- **Fish more efficient than other vertebrates**
- **Why?**
  - **Ectothermy vs. endothermy**
  - **Energy/matter required to counterbalance gravity**
  - **Bias of a high-protein diet**

Nutritional efficiency

- Maintenance ration (MR) = the amount of food needed to remain alive, with no growth or reproduction (% body wt./day)
- MR is temperature-dependent
  - MR increases as temperature increases
- MR is size-dependent
  - MR decreases as size increases