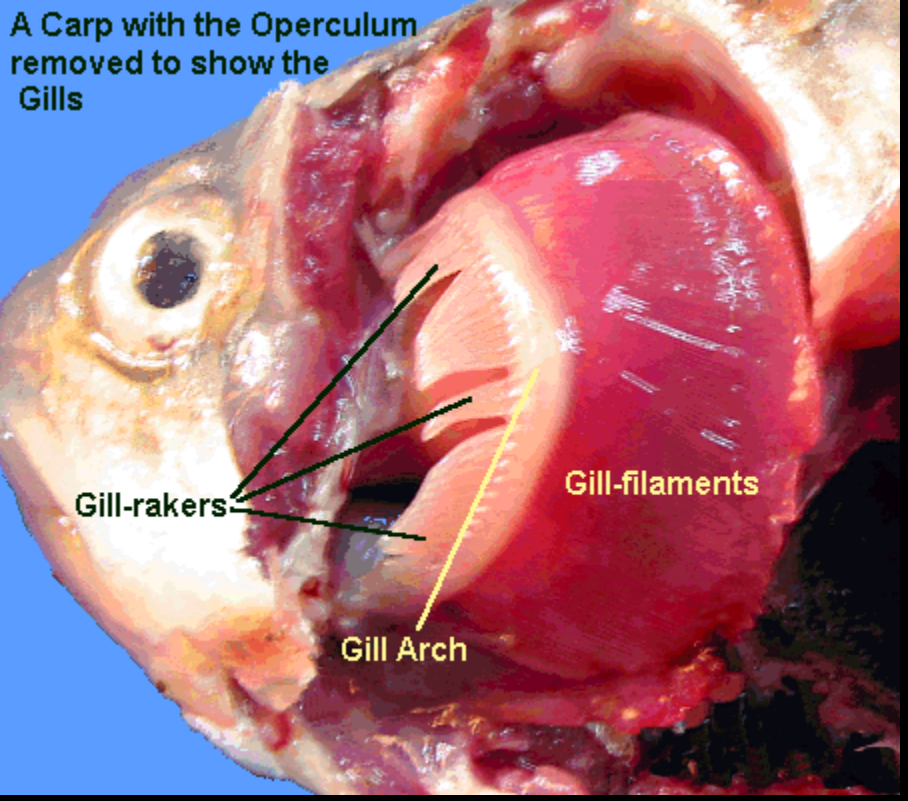
FISH PHYSIOLOGY & BREEDING
BS IV- SEMESTER 8

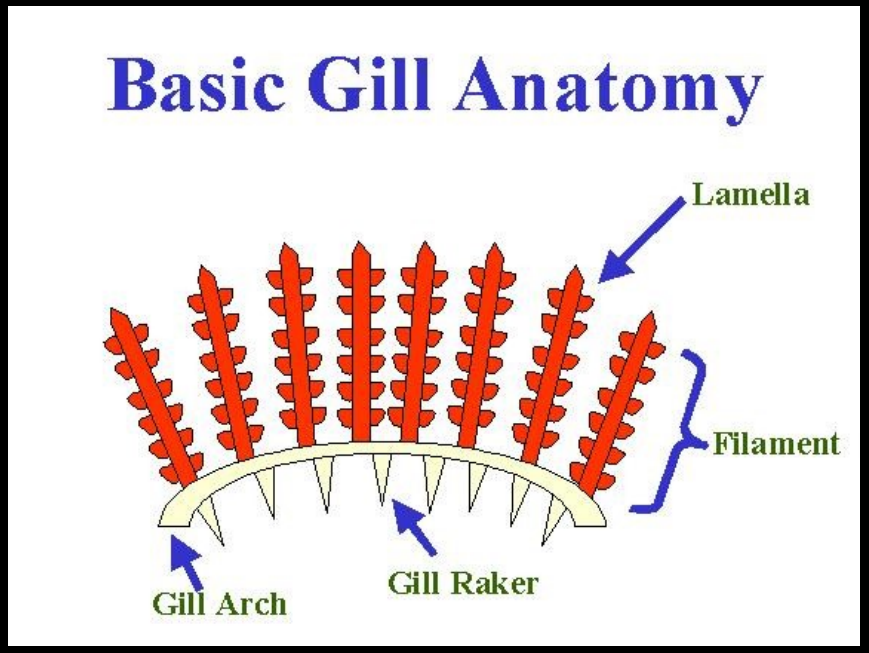
Feeding
&
Food Processing

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

Food capture

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


A Carp with the Operculum removed to show the Gills
Gill-rakers
Gill-filaments
Gill Arch


Basic Gill Anatomy
Lamella
Filament
Gill Arch
Gill Raker


1
2
3
4
5
6
7
8
9
10

Fish Feeding - function

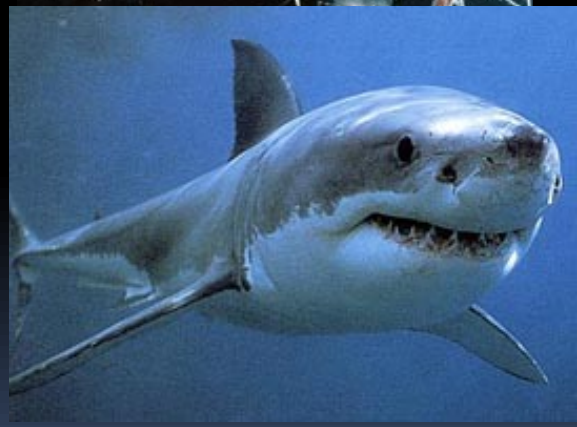
- Herbivores
  - < 5% of all bony fishes, no cartilaginous fishes
    - browsers - selective - eat only the plant
    - grazers - less selective - include sediments
- Detritivores
  - 5 - 10% of all species
  - feed on decomposing organic matter

Fish Feeding – function

- Carnivores
  - zooplanktivores
    - suction feeding
    - ram feeding (engulfing prey while swimming forward)
  - benthic invertebrate feeders
    - graspers
    - pickers
    - sorters
    - crushers

Fish Feeding – function

- More Carnivores
  - fish feeders
    - active pursuit
    - Stalking (hunt and kill)
    - Ambushing (sit and wait)
    - Luring (attract)



Fish feeding behavior

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

Feeding behavior

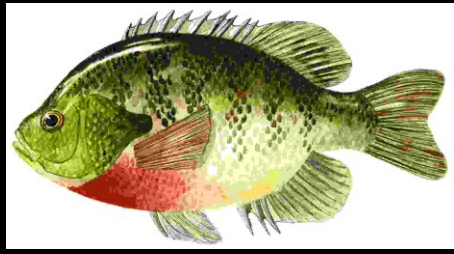
- Fish show versatility in **prey choice** and **ingestion**
- Behavior tightly linked to morphology

  (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

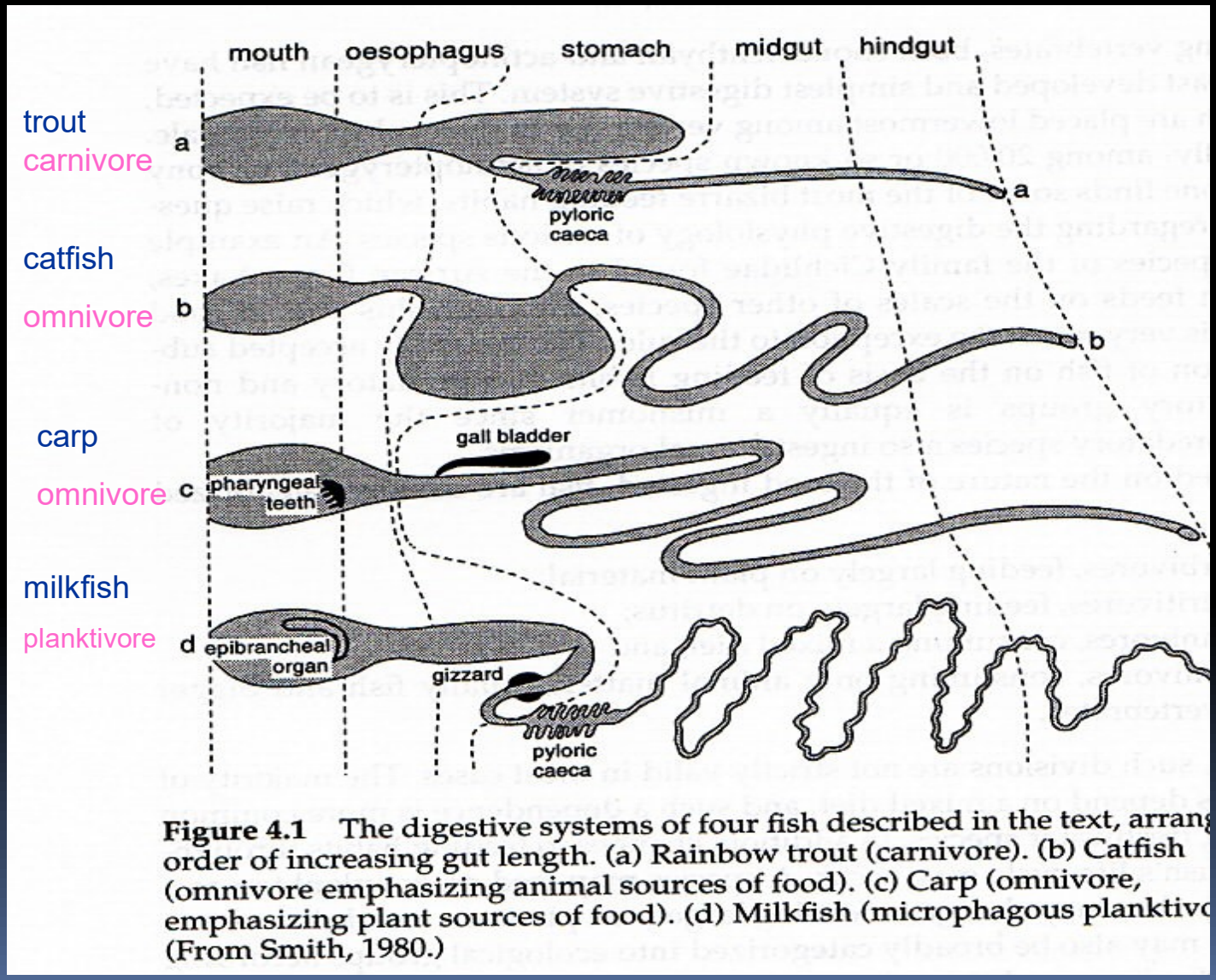


Figure 4.1 The digestive systems of four fish described in the text, arrang order of increasing gut length. (a) Rainbow trout (carnivore). (b) Catfish (omnivore emphasizing animal sources of food). (c) Carp (omnivore, emphasizing plant sources of food). (d) Milkfish (microphagous planktivo (From Smith, 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
- 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 (amino acid & carbohydrate absorption)
- 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
- *Common carp:* small mouth for bottom feeding, pharyngeal teeth (teeth in pharyngeal arch) , 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
- 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**
- 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)

Fish Nutritional Needs

- High protein diet

  - Proteins needed for growth of new tissue
  - Proteins moderately energy-dense (ectotherms, low gravity)
  - Few side-effects - ease of NH_4^+ excretion

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
  - Ectothermy vs. endothermy
  - Energy/matter required to counterbalance gravity
  - Bias of a high-protein diet

Components of Fish Diet
PROTEIN

- **30-50% in most fish diets**
- **IMPORTANT FOR FISH** – structure/muscle, gonads and growth
- Linear relationship between daily protein and growth
- Utilization of protein relatively constant and independent of feeding - (carnivore, omnivore, herbivore)

CARBOHYDRATES

- Not very important for most fish species
- Appear as sugars and starches
- Trout have limited ability to digest sugars/starches
  - May affect fish health
  - Catfish digest starch well

CARBOHYDRATES

- Fish lack the enzyme cellulase
  - Unable to break down cellulose
  - Fiber usually considered to have o nutritional value
- Levels of 10 to 20% have resulted in growth depression in rainbow trout

ESSENTIAL FATTY ACIDS

- Triglycerides with polyunsaturated fatty acids
  - *w* 3 and *w* 6 - Omega or linolenic series (n-series) of fatty acids
  - Digestibility of lipids is 85-95%
  - Major source is fish oil (salmonids) or soybean oil (ictalurids)

MINERALS

- Required by all animals – fish can uptake some from water
  - Formation of skeletal tissue
  - Respiration
  - Digestion
  - Osmoregulation (SW = high minerals/salts, FW = low
- Major minerals
  - Ca, Phos, Sulphur, sodium, chloride ion, K+, Magnesium
- Trace minerals
  - Cobalt, Copper, Fluorine, Iodine, Iron, Manganese, etc.

VITAMINS

- COMPLEX SUBSTANCES
- FAT SOLUBLE VITAMINS
  - A- Retinol - carotenoids converted in intestinal mucosa
  - E - Tocopherol - antioxidants in fish diets
  - K - Two forms in green plants - blood clotting and bacteriostatic (bacterial growth preventive)
  - D - calciferols not well understood

WATER SOLUBLE VITAMINS

- B_1 - coenzyme of carbohydrate metab
  - digestion, reproduction, nervous system
- B_2 - Riboflavin- eyes function
- B_6 - Pyridoxin
- Pantothenic acid
  - Fat & carb breakdown
- Inositol – improves reduced growth rates

WATER SOLUBLE VITAMINS

- Niacin – nervous system function
- Biotin – metabolism of fats and carbs
- Choline - improves growth and conversion
- Cyanocobalamic (B_{12})- nerve cells function & synthesis of nucleic acids
- Folic acid – brain function

WATER SOLUBLE VITAMINS

- Ascorbic Acid (C)
  - Important - Collagen skeletal systems
  - Wound healing, disease resistance
  - Fish and primates can not synthesize

Diet Additives: Hormones

- Hormonal control used to produce mono sex cultures of fish
- reduces reproduction/increases growth
- ex. Androgenic steroids (ethyltestosterone) fed to tilapia fry = 90% males
- does not work the same on all fish
- 17-alpha-methyltestosterone improves growth and survival in salmonids
- andorgenic better than estrogenic

Other dietary factors

- Attractants
  - Attract fish by sight or smell (shrimp meal, fish oil, fish meal, etc.)
- Pigments
  - External
    - Crayfish, red snapper
  - Flesh color – pink in salmon or trout
    -
    - Must be obtained from feed (crustaceans, yeast, plants/algae)

Physical Properties

- Ground meals are not suitable for feeding to aquatic animals due to poor ingestion, feed conversion, and reduced water quality
- pellets need to be stable in water until consumed by the target animal
- good pellet stability required for slow-feeding species such as shrimp
- particle size is important to insure appropriate consumption

various sizes of fish feed particles