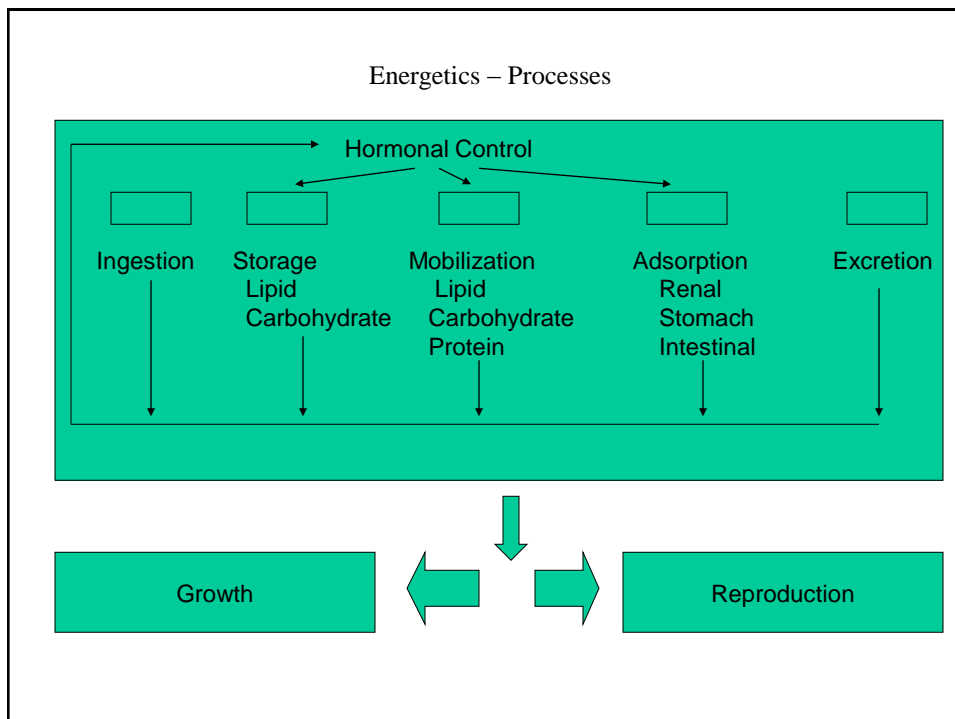


# Bioenergetics

## Growth, Nutrition

Some approaches to understanding  
the dynamic processes of feeding,  
digestion, somatic growth,  
reproduction, excretion



## Energy Budgets

### Intake ( I = Income)

- **Macronutrients**
  - Carbohydrates
  - Lipids
  - Proteins
- **Micronutrients**
  - Vitamins
  - Essential
    - Fatty Acids
    - Amino Acids
    - Sugars

### Energy Use (E = Expenditure)

- **Respiration**
- **Osmoregulation**
- **Movement**
- **Feeding**
- **Digestion**
- **Reproduction**

### IF

$I = E$     **Growth = 0**

$I < E$     **Growth = -**

$I > E$     **Growth = +**

## Gross Constituents of Body or Foods – macro and micro

- Protein
- Lipids
- Carbohydrates
- Water
- Ash that includes minerals
- Vitamins are required to supplement metabolic processes

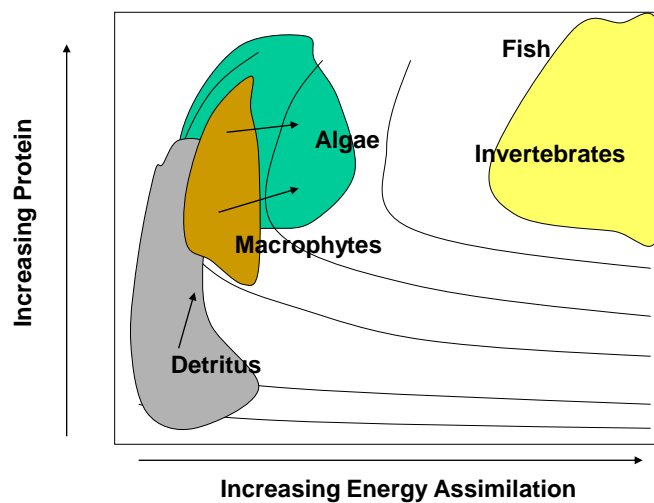
## Proteins

- Major organic constituents of fishes
- 65 – 75% of dry weight of teleost tissues
- Dietary requirements of fishes of protein are 2 – 4 X higher than other vertebrates
- Utilization falls within range of all vertebrates

- Proteins are essential parts of organisms and participate in every process within cells.
- Many proteins are enzymes that catalyze biochemical reactions and are vital to metabolism
- Proteins also have structural or mechanical functions, such as actin and myosin in muscle and the proteins in the cytoskeleton, which form a system of scaffolding that maintains cell shape.
- Other proteins are important in cell signaling, immune responses, cell adhesion, and the cell cycle.

- Animals cannot synthesize all the amino acids they need and must obtain essential amino acids from food.
- Through the process of digestion, animals break down ingested protein into free amino acids that are then used in metabolism

### Protein Based Energy Assimilation General Energy Relationships



## Lipids

- Supplies a large proportion of energy requirements
- Largely derived from diet, not bio synthesis
- Fatty acid composition varies nutritionally essential n-3 fatty acids are  $\alpha$ -linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) (DHA:22:6n-3).
- Lipid source of energy for growth and reproduction

## Essential

- 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

- Fish vary in efficiency of using carbohydrates
- Fewer herbivores thus less data on this aspect
- Some grazing species may be able to use and utilize gastrointestinal symbioses with microorganisms.

- carbohydrates are stored as glycogen and do not yield as much energy in fish as in mammals.
- Understanding of role in nutrition is still in flux

## Fish Types by Diet Choice (may change over life cycle)

- Herbivores
  - Phytoplankton
  - Macrophytes
- Carnivores
  - Zooplankton
    - Selective (High Cost but Food Specific)
    - Non-Selective (Low Cost but Non Specific)
  - Benthic (Live in Water Column, but Feed Off Bottom)
  - Fish Feeders (Ichthyvores or Piscivores)
- Detritivores

## Food types, components and diets

- Foods eaten are mixture of nutrient and non nutrient components
- All fishes require approximate 40 nutrients
- Macronutrients: protein lipid and carbohydrates

## **Digestion- First Phases (Mechanical)**

- Mechanical – Jaws
  - Winnowing – Cichlids (Sort Chaff from Food)
  - Flat Plate Jaws – Grinding
  - Short Teeth – Grinding and Tearing
  - Elongate Sharp Teeth - Shearing
- Mechanical – Pharyngeal Jaws and Plates
- Gill Rakers - Sieving
- Gizzard Like Modifications - Menhaden

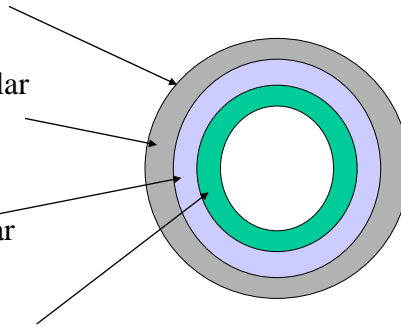
## **Food Processing - anatomy**

- Esophagus –
- Stomach -
- Pyloric caecae
- Intestine – (anterior and posterior or proximal and distal)
- Pancreas and Liver



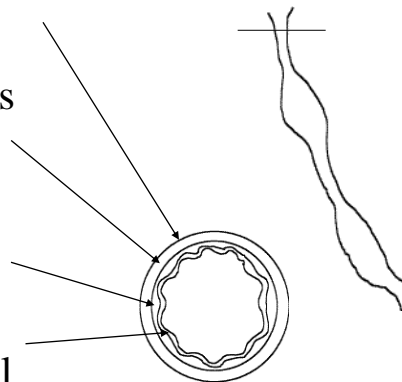
## The Gastrointestinal System The Generalized Tract

- Serosa/Adventitia – External Covering or Shared Connective Tissue
- Tunica Muscularis – Circular and Longitudinal Muscle Masses
- Tunica Submucosa – Connective Tissue, Vascular Supply, Nerves
- Tunica Mucosa – Internal Lining, Absorptive Surface



## The Esophagus

- Serosa/Adventitia – A transition
- Muscularis – Muscles More Spiral and in Opposition
- SubMucosa – Thin
- Mucosa – Stratified squamous to cuboidal

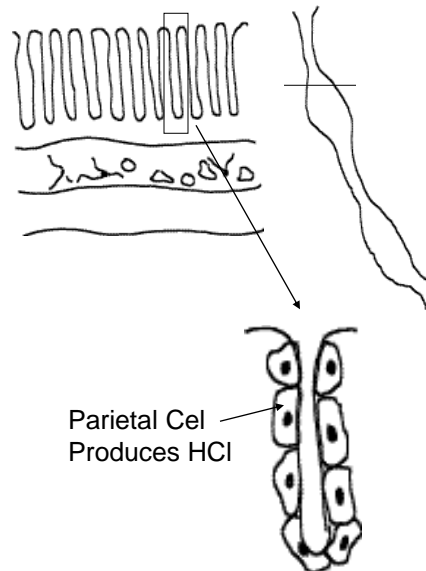


## Stomach - Breakdown with digestive enzymes and gastric juices and or mechanical disruption

- Gastric mucosa contain cells that secrete pepsin and HCL
- Endocrine cells that secrete hormones including gastrin and somatostatin
- Mucous cells

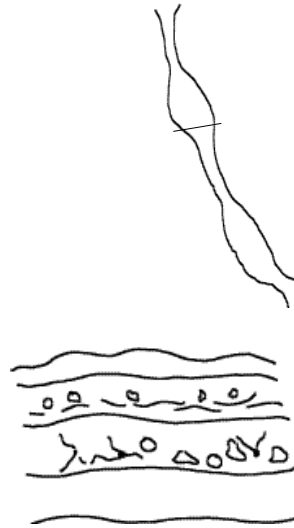
## The Stomach- Anterior or Fundic

- Adventitia to Serosa
- Muscularis – Arranged as Spiral Bands in Opposition
- Submucosa – Thick
- Mucosa – Cuboidal to Columnar with Deep Pits Lined by Parietal Cells – Secrete HCl



## The Stomach – Posterior or Cardiac

- Primarily Serosa
- Muscularis – Spiral Bands in Opposition
- Submucosa – Thick
- Mucosa – Stratified Squamous

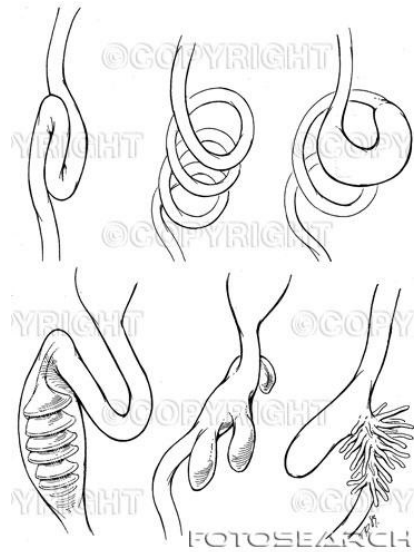


## Variety of stomach types

- No stomach
- Straight – pike channel cats, halibut
- U shaped - salmonids
- Y shaped – eels, tilapia, lingcod
- Absent – carp, suckers, Most of these species have pharyngeal mechanism for processing

## Stomach - Modifications

- Agastric
  - Short Straight – Carnivores
  - Long Straight – Herbivores
  - Simple - Carnivores
- Gastric
  - Spiral Valves – Elasmobranchs
  - Cecate – Herbivores
  - Diverticulate – Herbivores and Carnivores



## pH in Stomach and Intestine

- Gastric acidity varies
- Herbivores 1.9 to 4.3
- Plasma membrane of most macroalgal cells ruptures at pH 2 to 4. Low stomach pH emulsifies lipids, denatures proteins and carbohydrates

## Digestion – Chemical

- Stomach – Acid Lysis, Acid Activation of Pepsinogen
- Enzymatic –
  - Anterior Small Intestine Site of Initiation
  - Length of SI Related to
  - Most Pancreatic Enzymes Operate at pH 7 – 9
  - Bile Contains Bicarbonates to Buffer
  - Cellulase Produced by Microbes and Larger Gut Size Produces Fermentation Vat
  - Chitin also via Chitinase and Microbes producing N-acetylglucosamine

## Pyloric caecae

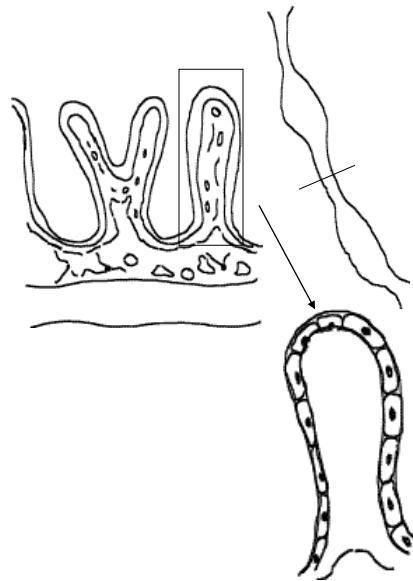
- Unique to fish
- Better developed in carnivores, esp. those with short guts
- Not associated with microbial fermentation
- Blind fingerlike projections of proximal intestine
- Absent in agastric fishes
- Serve to increase effective absorptive surface of anterior intestine (proximal)

## Intestine

- Extremely variable
- Proximal and distal
- Many the diameter different
- Intestine length is developmentally plastic and can increase in response to lower environmental temp and increase in proportion of small material (macrophytes, algae)

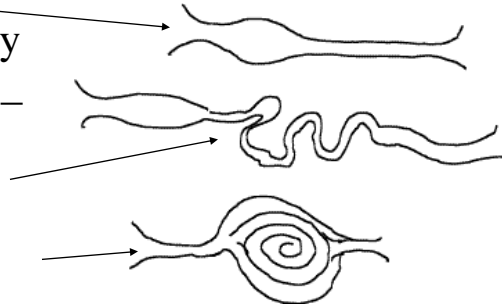
### The Anterior Intestine (small??)

- Adventitia/Serosa – Intermingled
- Muscularis – Primarily Circular with External Longitudinal Bands
- Submucosa – Thick with large arteries and veins
- Mucosa Divided into
  - Limiting muscle band
  - Lamina propria – connective tissue and vascular supply
  - Mucosa



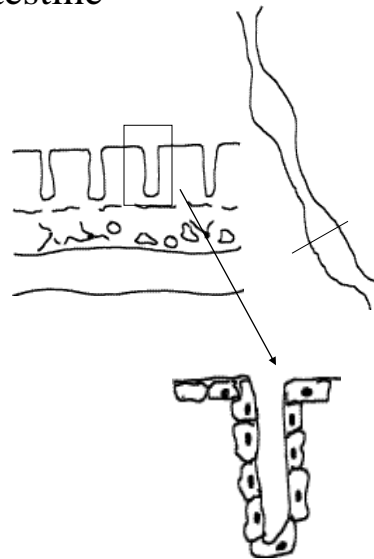
### Small Intestine - Modifications

- Simple –  
Insectivores Usually
- Elongate Complex –  
Carnivores
- Spiral - Herbivores



### Posterior Intestine

- Serosa Primarily
- Muscularis – Thin  
Circular, Longitudinal  
Muscle Bands
- Submucosa – Moderate  
Thickness
- Mucosa – Thin  
Muscularis Mucosa,  
Crypts Lined with  
Mucus Secreting Cells



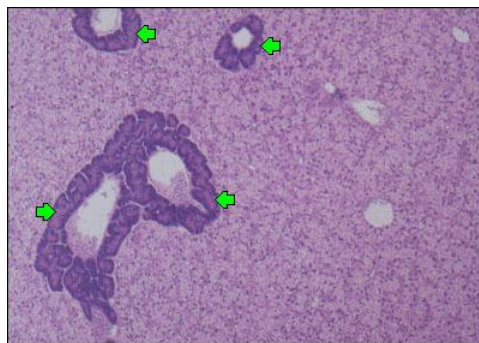
## Pancreas and Liver

- Exocrine pancreas (secretory) in fishes can form one or two discrete organs, or be diffuse spread through the adipose, mesentery, intestinal wall and liver
- Liver is discrete lobate. Variable in form, and interdigitates with intestine in some fish. Lipid store in many species, and bile secretion.
- Gall bladder present in most fish, connected to intestine by bile duct.

**Cod liver oil** is a nutritional supplement derived from liver of cod fish. It has high levels of the omega-3 fatty acids, EPA and DHA, and very high levels of vitamin A, and vitamin D. It is widely taken to ease the symptoms of arthritis as well as other health benefits.

**Docosahexaenoic acid**

**Eicosapentaenoic acid**





## Endogenous vs digestive enzymes

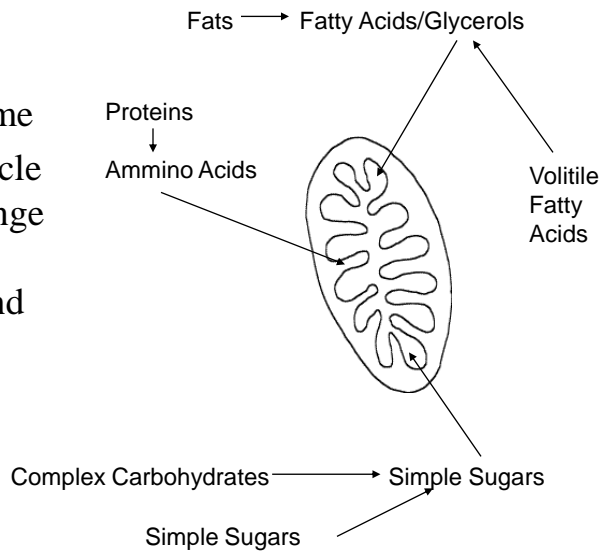
- Endogenous – can be extracellular membrane linked, and intracellular
- Carbohydrases, proteases, and lipases
- Protease and peptidase activities show complex and variable relationships to dietary habitats.

## Metabolism – Storage Sites in the fish

- Glycogen
  - Liver, Brain
- Lipid/Fats
  - Brain, Adipose Tissue, Liver, Red Muscle (Some Species)
- Proteins
  - All Cells, Muscle

## Digestion - Chemical (Continued)

- Enzymatic Variation – Some
- Note Krebs Cycle is Main Exchange Point For Conversions and Energy Production



## Digestion – Chemical (Continued)

- **Microbial**
  - Again View Relation to Gut Size
  - Significance of Microbial Balance
    - Tilapia
    - Carp
  - Temperature Effects – Cold Temperatures Represent a Problem

## Temperature Effects on Digestion

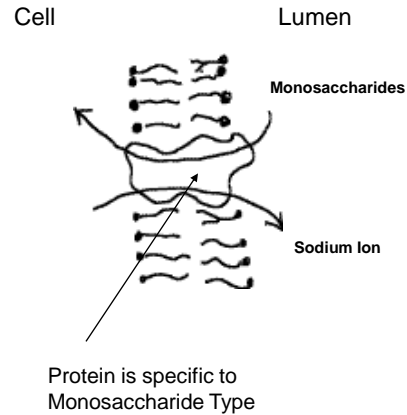
- Low temp can affect digestion by inhibiting reaction rates of enzyme catalyzed reactions
- Fishes in cold areas compensate by producing more, or changing the type of enzyme expressed, or having cold adapted enzymes with lowered temp optima (*psychrophilic*)

## Absorption Lipids

- Lipids
  - Bile Emulsification
  - Absorption
  - Conversion to Lipoproteins (Complex Aggregates of Macromolecules)
  - Volatile Fatty Acids Directly Absorbed (Small Sized Molecules with polar/nonpolar groups)

## Absorption (Continued) Carbohydrates

- Active Co-transport (Anti-transport) of Simple Sugars
- Sodium Ion – Moves out Passively in Response to Solute Gradient
- If Protein Gates Saturated no Further Absorption
- Cellulose, Though Complex Carbohydrate is Fermented into Volatile Fatty Acids



## Absorption Proteins

- Mono-peptides (Amino Acids)
  - CoTransport (Antiport) via Na Linked System
  - Movement Between Cells
- Di-peptides
  - CoTransport (Antiport)
  - Pinocytosis
- Poly-peptides
  - Pinocytosis

