Advanced Fish Feeding

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Fish Feeding – Syllabus

1- Introduction

2- Fish Nutritional Needs

3- Feeding and Digestion

4- Digestive Processes

5- Control and Regulation of Digestion

6- Nutrient Metabolism

7- Digestibility

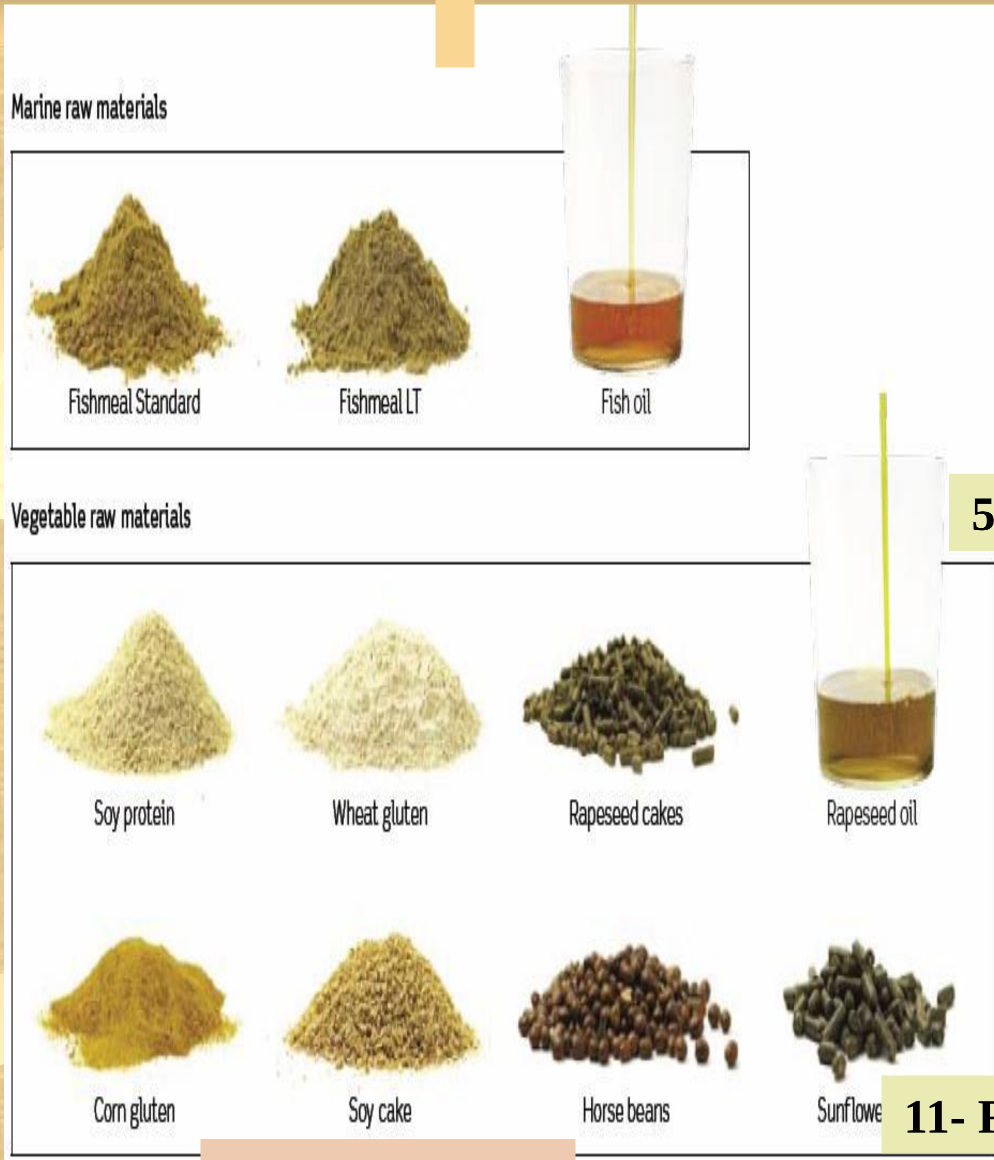
8- Nutrition Physiology

9- Anatomy and Diet

10- Sensory Organs

11- Food Capture Structures and Organs

12- Experimental Design in Feeding Experiments



Feed materials

Report on Fish feedin **Ref.(Halver,2002)&Hepher,1988)**

Fish feeding categories

Fish can be broadly grouped into the following feeding categories:

Carnivores - eat animal food

Piscivores - fish eaters

Benthophages - eat animals living in or on sediments

Epifauna eaters - feed on prey living on the bottom substrate, e.g. scrape or bite prey from stones or rocks

Infauna eaters - feed on prey that burrow in the bottom sediments, e.g. prey are buried in sand or mud

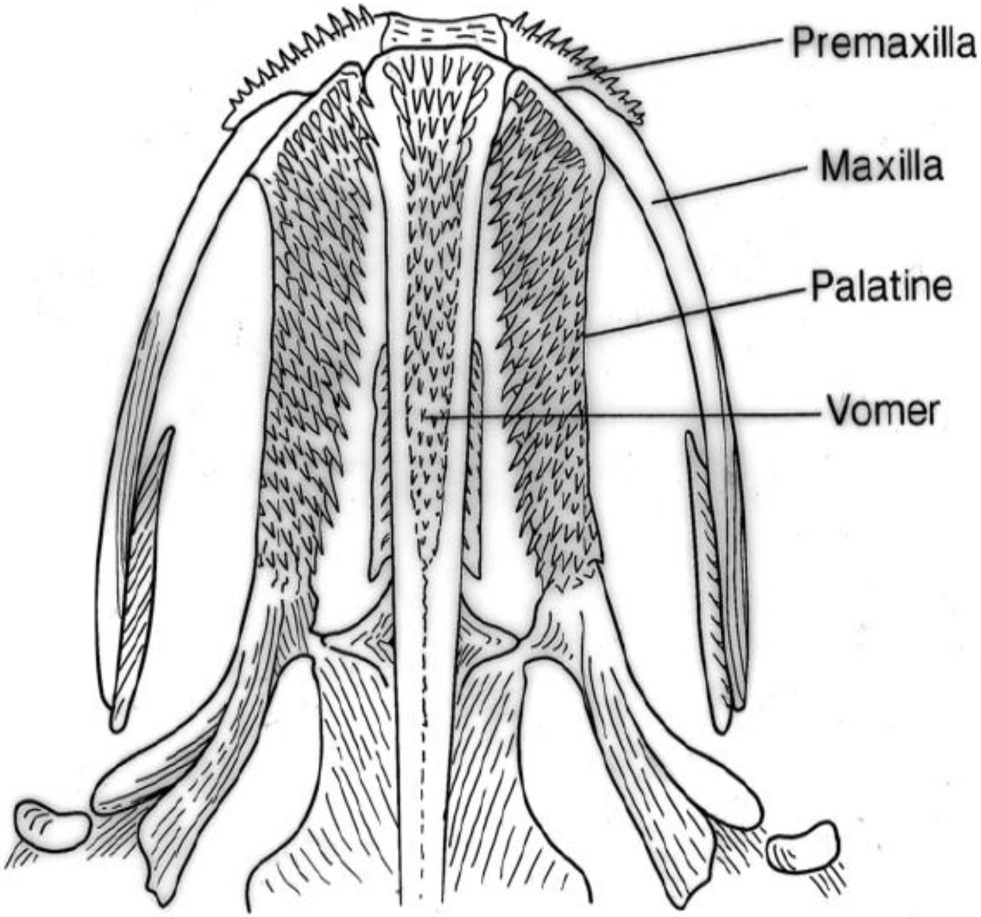
Zooplanktivores - eat planktonic animals

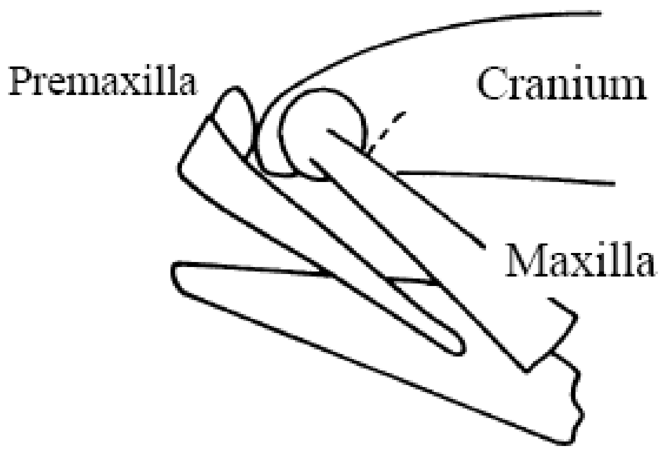
Parasites

Omnivores - eat both plant and animal food

Herbivores - eat plant food .Feed on large algae and water plants Filter phytoplankton and microalgae from the water

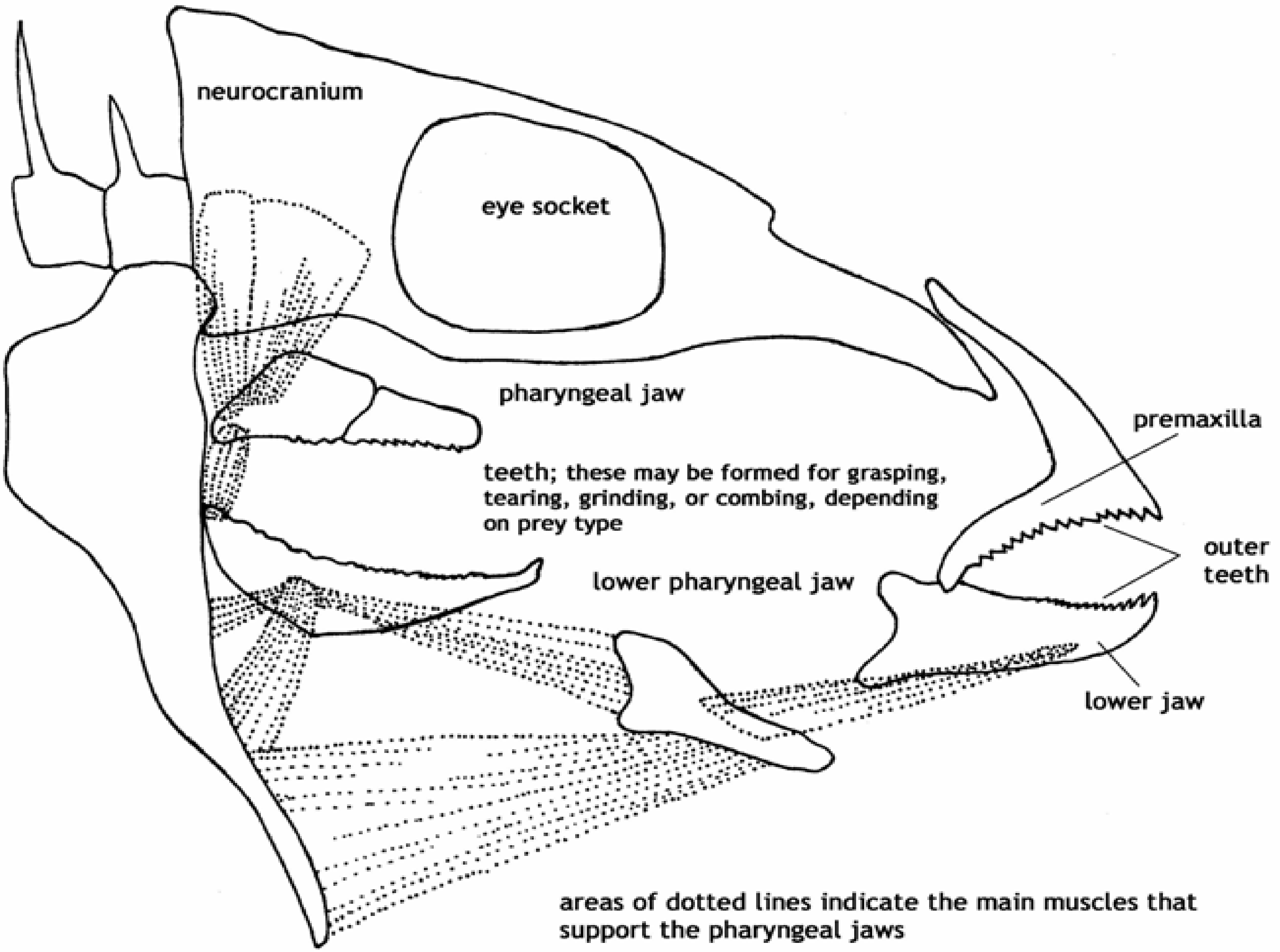
Detritivores - eat detritus (sedimented organic matter, bacteria, fungi and encrusting microalgae)





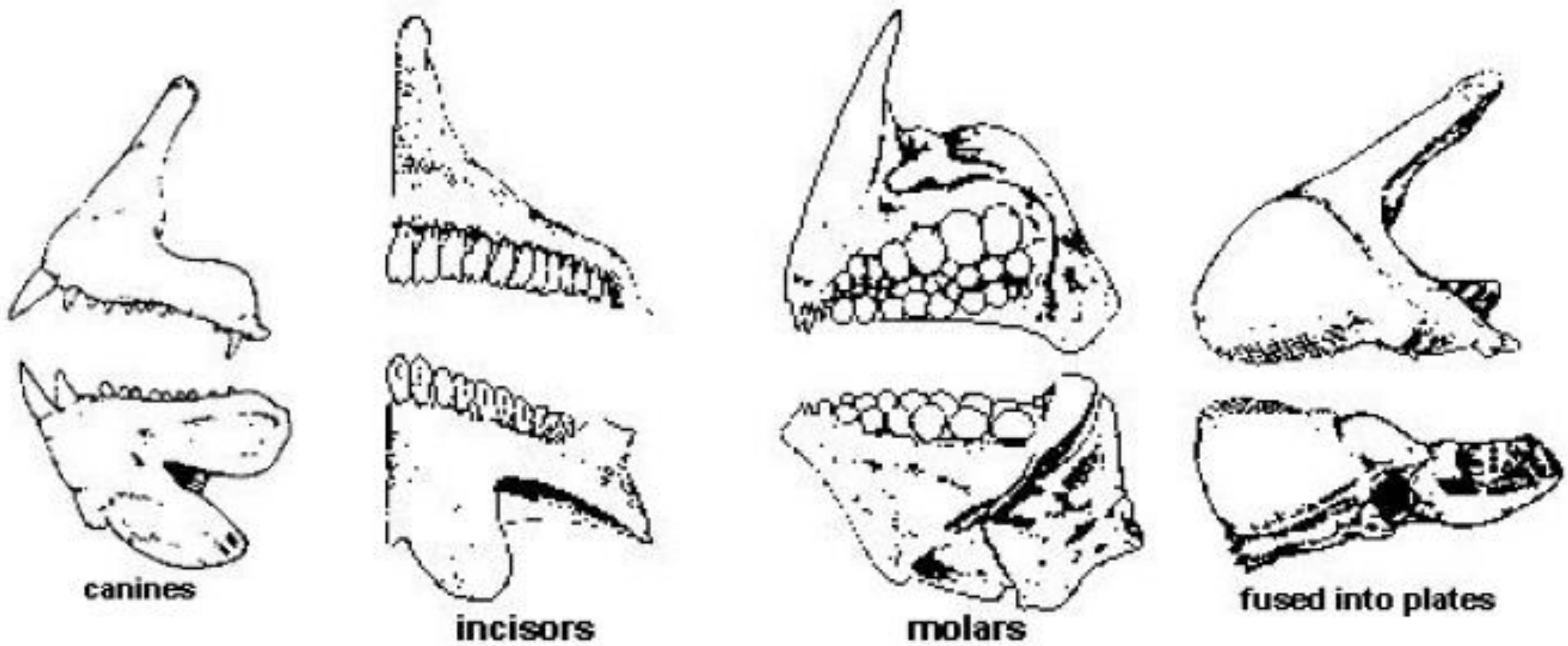
In addition to the jaw teeth and those in the mouth, many species of fish have specialised teeth (for crushing or grinding) in the pharynx ('at the back of the throat').

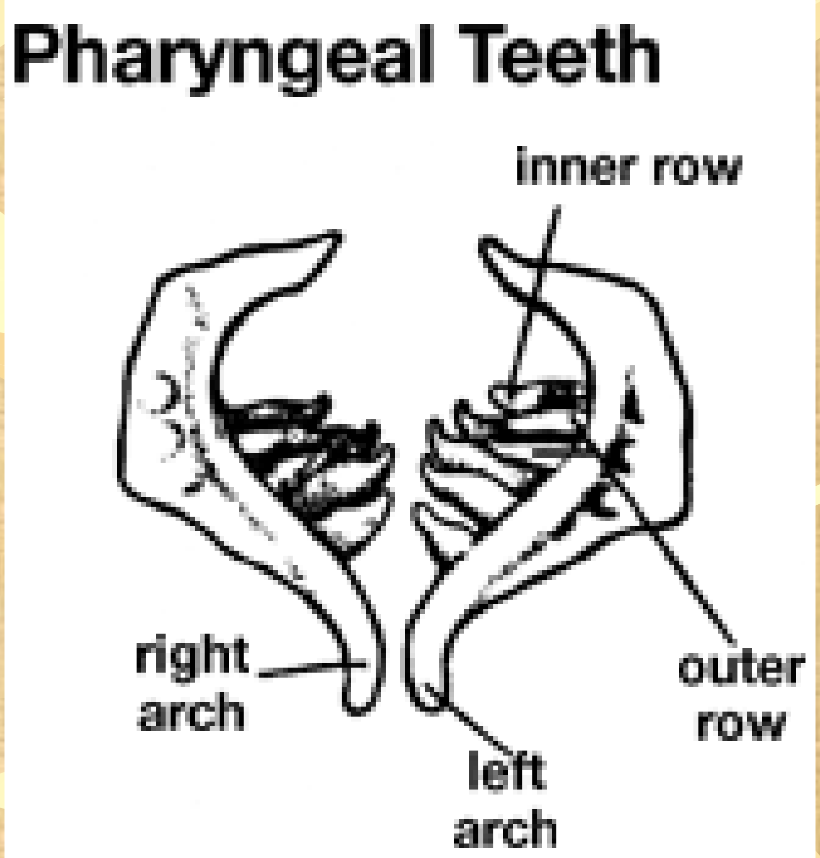
These teeth are often called the **pharyngeal mill**



neurocranium
eye socket
pharyngeal jaw
premaxilla
teeth; these may be formed for grasping, tearing, grinding, or combing, depending on prey type
outer teeth
lower pharyngeal jaw
lower jaw
areas of dotted lines indicate the main muscles that support the pharyngeal jaws

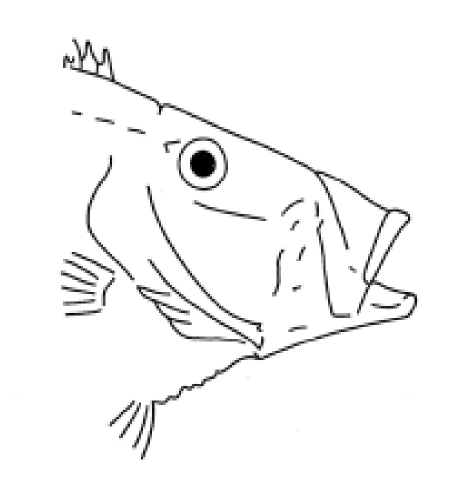
Fish Teeth

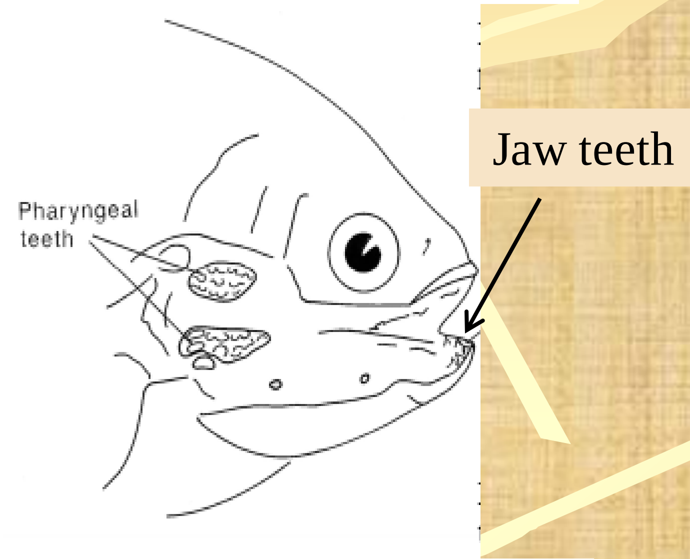



Pharyngeal Teeth
inner row
right arch
outer row
left arch

A distensible tubular mouth enables the generation of suction pressure.

Suctorial feeding may be used for feeding on zooplankton, or small benthic animals that are either burrowed in bottom sediments (infauna) or are loosely attached to the bottom substrate (epifauna).





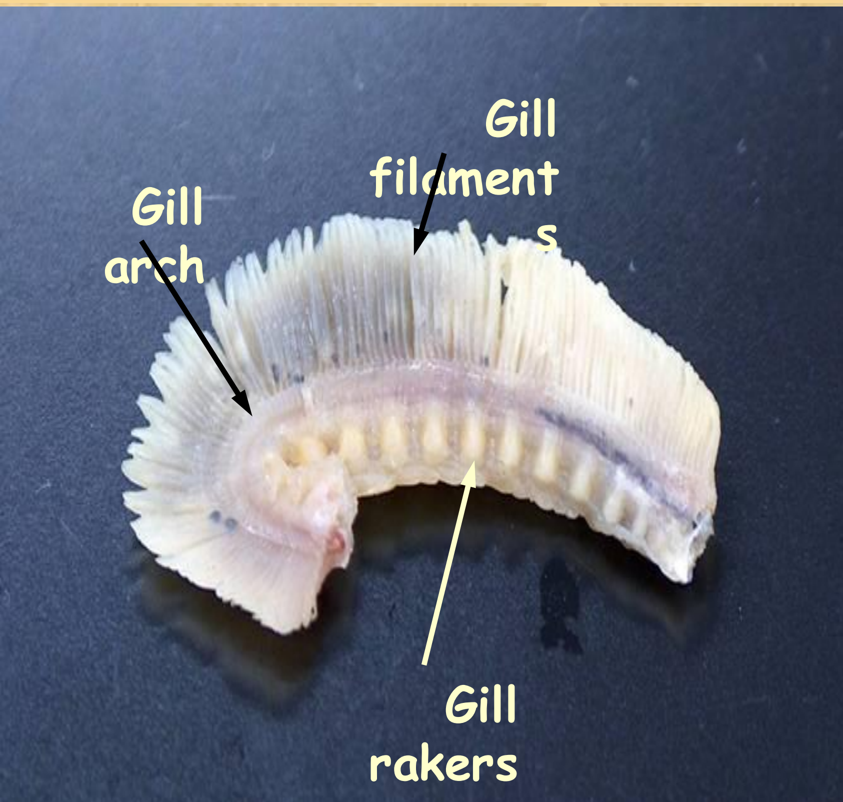
Feeding on strongly-attached epifauna, and animals with heavy ‘shells’, requires powerful ‘molariform’ jaw teeth.

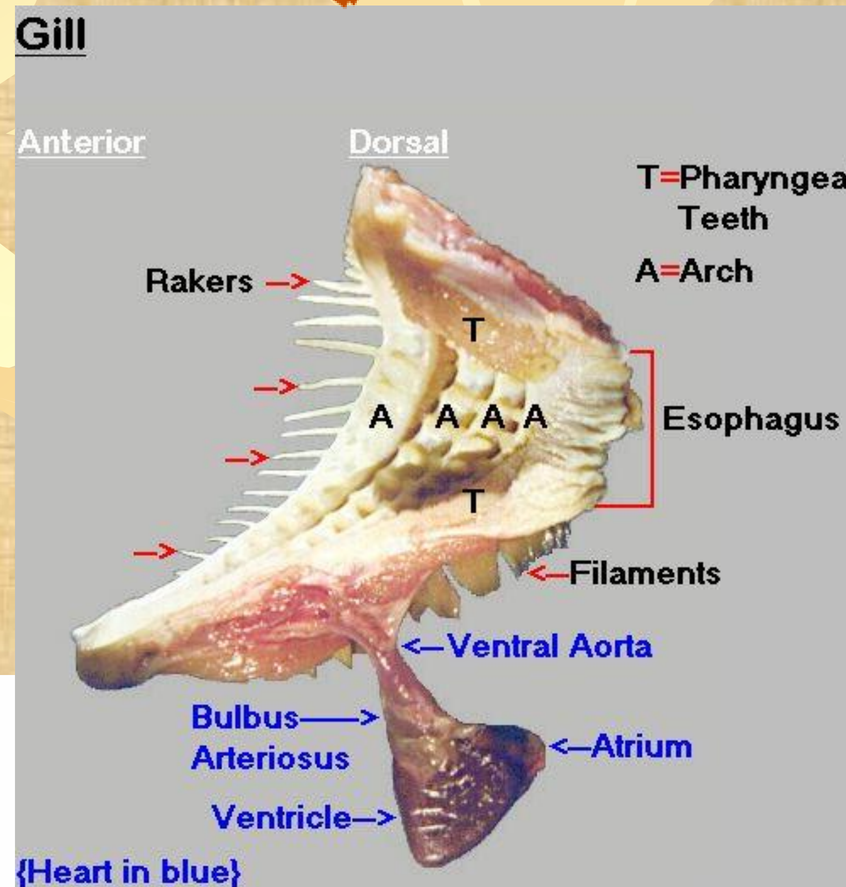
Sets of ‘blunt’ molariform teeth in the pharynx (the pharyngeal mill) serve to crush and grind the ‘shells’ of the prey.

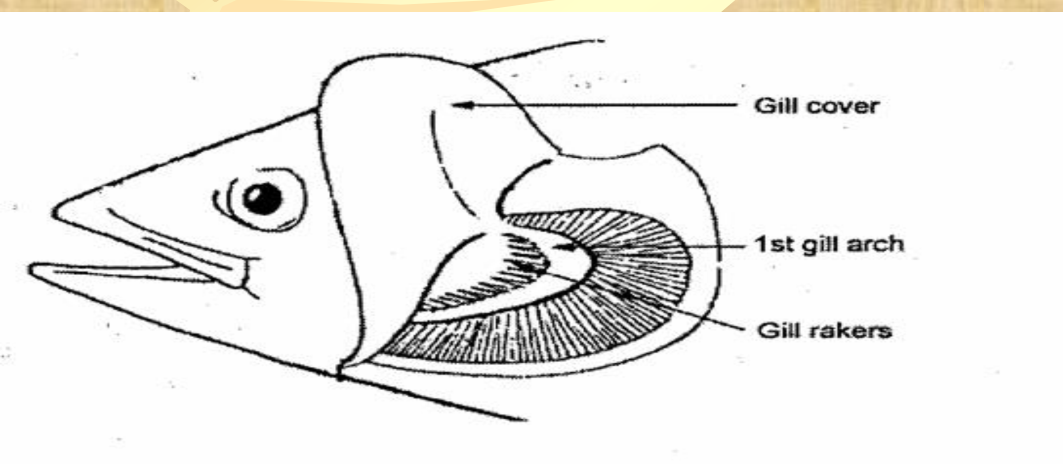
Herbivorous species may also have well-developed pharyngeal teeth to break down the plant material into a semi-liquid ‘slurry’ before it is swallowed.

Gills and Gill Rakers

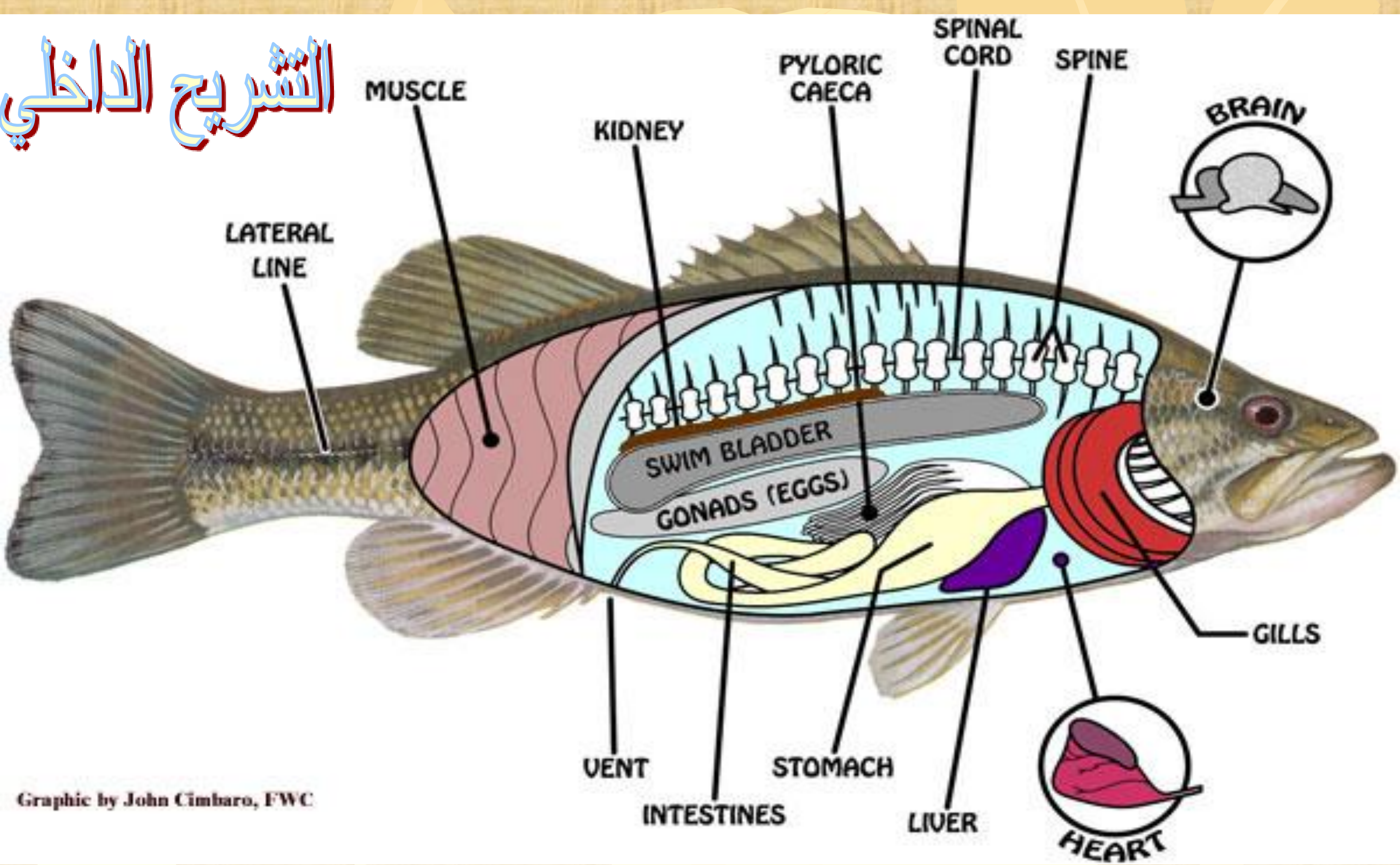
الغلاصم في الأسماك







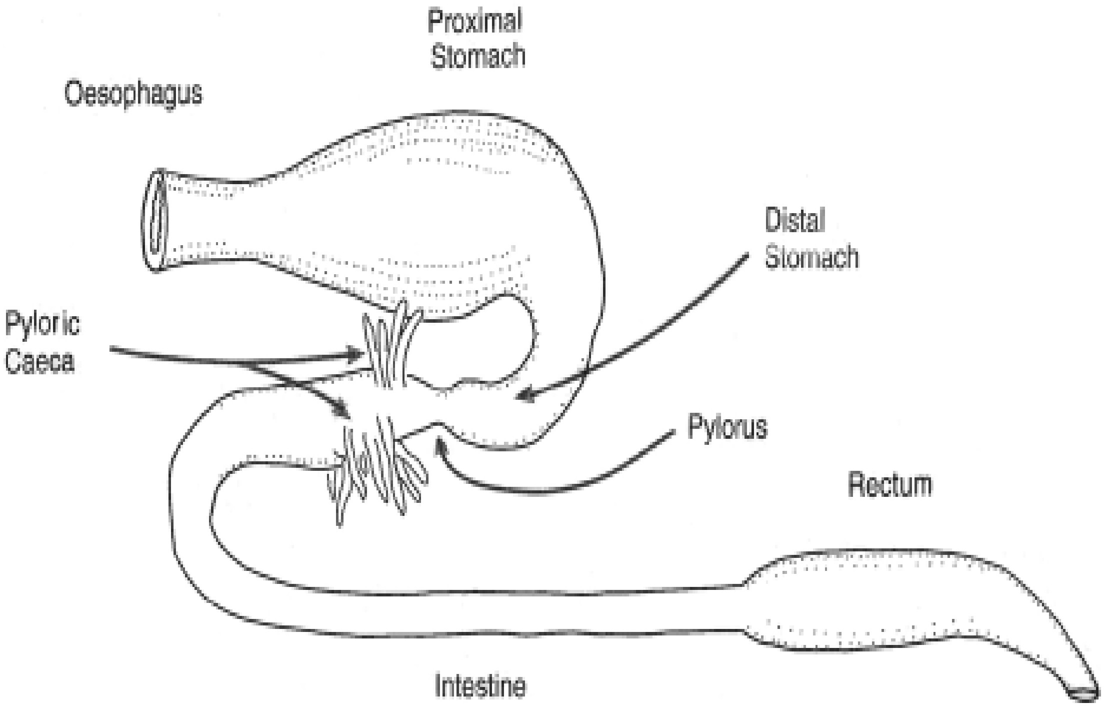
التشريح الداخلي

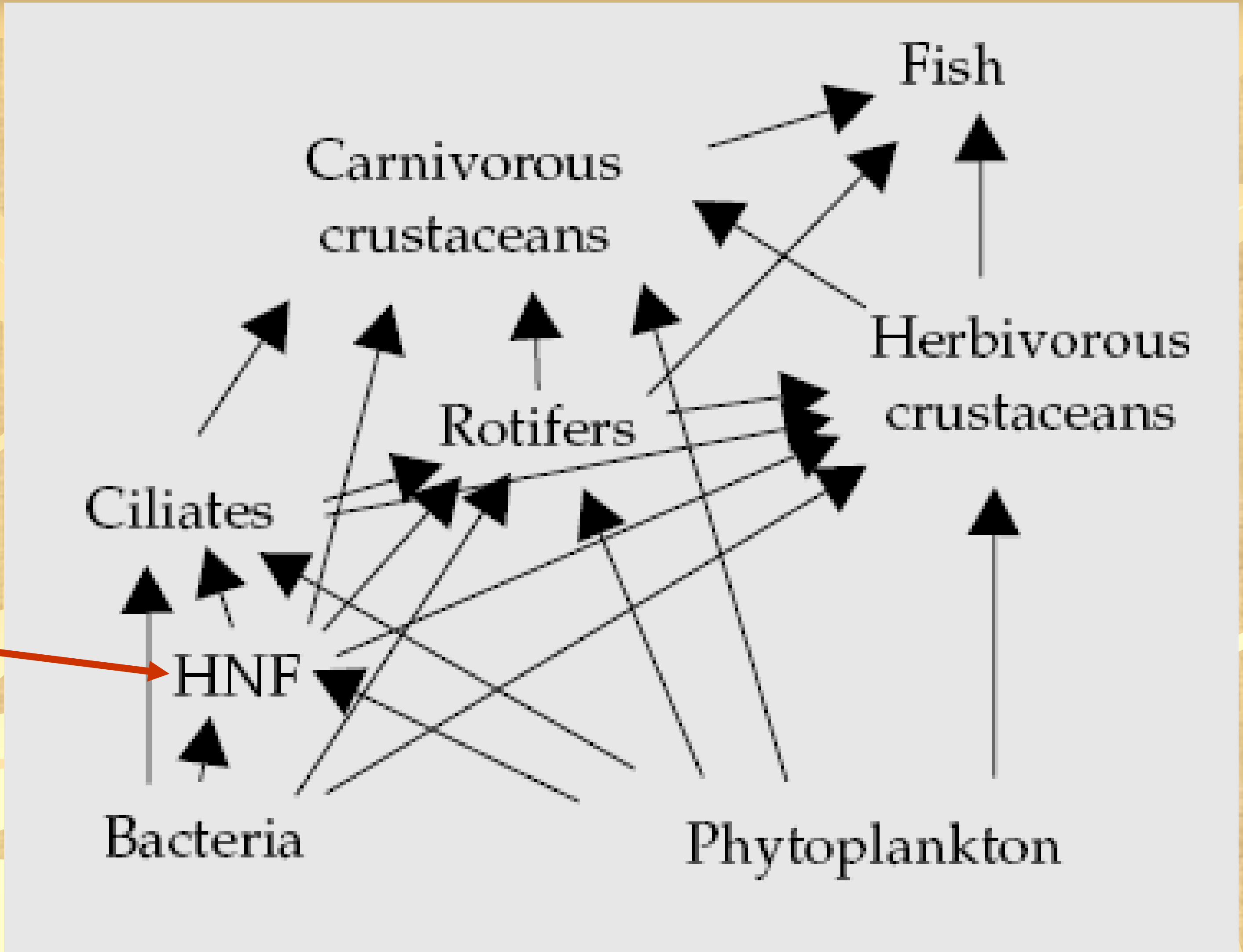


The alimentary canal (digestive tract or gut)

The digestive tract is made up of the:

- **mouth and buccal cavity**
- **pharynx**
- **oesophagus**
- **stomach**
- **intestine (and pyloric caeca)**
- **rectum and anus**
- **accessory organs (liver, gall bladder and pancreas)**





heterotrophic nanoflagellates

Food web into eight trophic

Diet Composition

2- Fish Nutritional Needs

Diets comprise three major constituents in the form of proteins , fats and carbohydrates plus three or four minor ingredients in the shape of vitamins, minerals, water and, for older salmonids in particular, pigments.

Just as nutritional requirements change as animals age, so the composition of fish diets alters as the fish goes through its various developmental stages. Naturally those involved in fish feed formulation need to know the nutritional requirements of a particular stock species and the means by which these can best be met to give maximum growth in a cost-effective manner. An obvious starting point is to look at what the stock would eat in the wild at various life cycle stages, to ascertain nutritional profiles and attempt to replicate them. This is indeed what happens - most proprietary fish diets are based on piscine raw materials.

Within modern aquaculture, a stocks' nutritional needs can be met using different types of diet depending on the stock being cultured and what life cycle stage is involved.

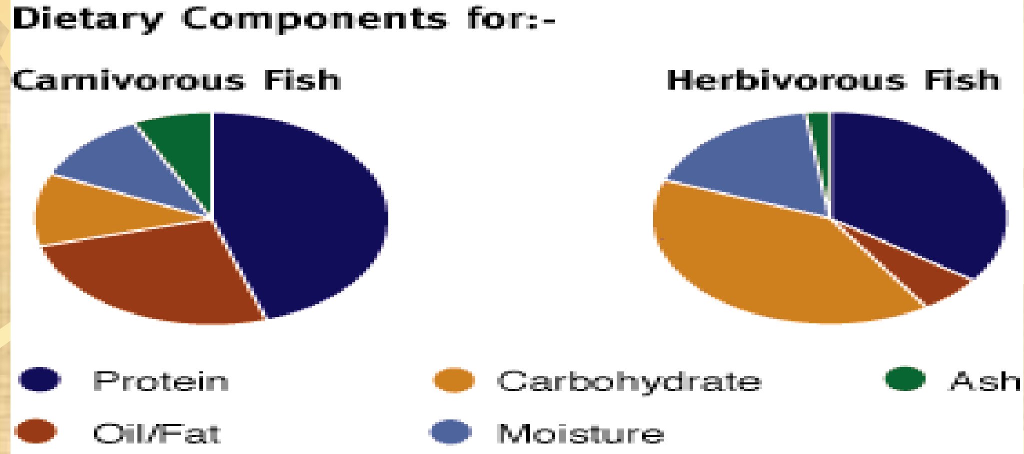
For herbivorous and omnivorous species (such as cyprinids) under extensive or semi-intensive culture, a natural food supply is utilised with, in the latter type, some supplemental fertilisation of holding units to encourage plant and plankton growth.

A variety of diet types can be utilized for carnivorous species ranging from wet (minced/diced raw fish) through moist (basic fish meal and additives mixed on site with freshwater) to the well-known modern pelleted diets. For some species a live diet is required during larval development, as in the feeding of *Artemia* to larval halibut and cod

Whatever diet is used, it must be nutritionally balanced to meet the energy budget of the stock so as to optimize growth and profit. Total energy value of diets will vary with the proportion of its various ingredients. As fish regulate their energy intake to match their energy needs, they in effect regulate the absolute amount of proteins that they ingest. Thus the balance of ingredients in a diet may be more important than definitive levels of one particular nutritional component. Consequently diets deemed to be 'low energy' ones may result in as much growth as a 'high energy' one, provided it is nutritionally balanced.

Dietary Components

The main components of fish diets, man-made or natural are:



Protein

Carnivorous fish, such as salmonids, require diets rich in protein (about 40 - 50% content) compared to omnivorous or herbivorous fish such as carps (typically 25 - 35% content) for optimal growth.

Proteins are composed of a number of building blocks known as amino acids. Different proteins are formed from around 20 known amino acids, the calorific value (energy worth) depending on the amino acids present, their arrangement(s) and availability following absorption. Fish appear to be incapable of synthesizing 10 amino acids totally or in sufficient quantities to meet their needs - these are referred to as essential amino acids and must be present in their original, pure form in any diet. The non-essential amino acids can be either synthesized from their basic raw materials (carbon, oxygen, hydrogen and nitrogen) or interconverted from other amino acids.

Proteins

The proteins are among the most important constituents of all living cells and represent the largest chemical group in the animal body, with the exception of water; the whole fish carcass contains on average 75% water, 16% protein, 6% lipid, and 3% ash. Proteins are essential components of both the **cell nucleus** and **cell protoplasm**, and accordingly account for the bulk of the muscle tissues, internal organs, brain, nerves and skin

Composition

Proteins are very complex organic compounds of high molecular weight. In common with carbohydrates and lipids, they contain carbon (C), hydrogen (H), and oxygen (O), but in addition also contain about 16 % nitrogen (N: range 12–19%), and sometimes phosphorus (P) and sulphur (S).

Structure

Proteins differ from other biologically important macromolecules such as carbohydrates and lipids in their basic structure. For example, in contrast to the basic structure of carbohydrates and lipids, which is often composed of identical or very similar repeating units (ie. the glucose repeating unit within starch, glycogen and cellulose), proteins may have up to 100 different basic units (amino acids). It follows therefore that greater compound variabilities and ranges are possible, not only to composition, but also to protein shape.

تقسيم البروتينات Proteins Classification

1-Fibrous protein: غير ذائبة ومقاومة للأنزيمات الهاضمة سلاسل من خيوط متطاولة من

امثلتها:

Collagens	Elastin	Keratin
connective tissue	arteries	hair & wool

2-Globular proteins: تشمل جميع **enzymes, antigens, hormone**

يمكن تقسيمها الى:

1-albumins: **ذائبة تتجلط بالحرارة موجود بالبيض والحليب والدم**

2-globulins: **غير ذائبة او قليلة الذوبان بالماء تمثل مخزون البروتين بالبذور النباتية**

3- histones: **بروتين ذو وزن جزيئي واطئ ذائب نواة الخلية مرتبط مع DNA**

3-Conjugated proteins: **ينتج مجاميع غير بروتينية اضافة للأحماض الامينية عند تحللها وتشمل**

phosphoproteins **في كازين الحليب ومح البيض** glycoproteins **افرازات مخاطية** lipoproteins **غشاء**

الخلية chromoproteins **هيموغلوبين** nucleoproteins **احماض نووية**

وظيفة البروتين Protein function

- تعويض الانسجة التالفة
- اعادة بناء الانسجة
- بروتين العليقة مصدر للطاقة او هيكل لتركيب الدهون والكاربوهيدرات
- بروتين العليقة ضروري لتركيب الهرمونات والانزيمات والعديد من المركبات البايولوجية المهمة مثل الهيموغلوبين والاجسام المضادة

احتياجات البروتين Protein requirements

احتياجات بروتين العليقة في الاسماك

دراسات الحيوانات المدجنة

تجارب تغذية مختبرية

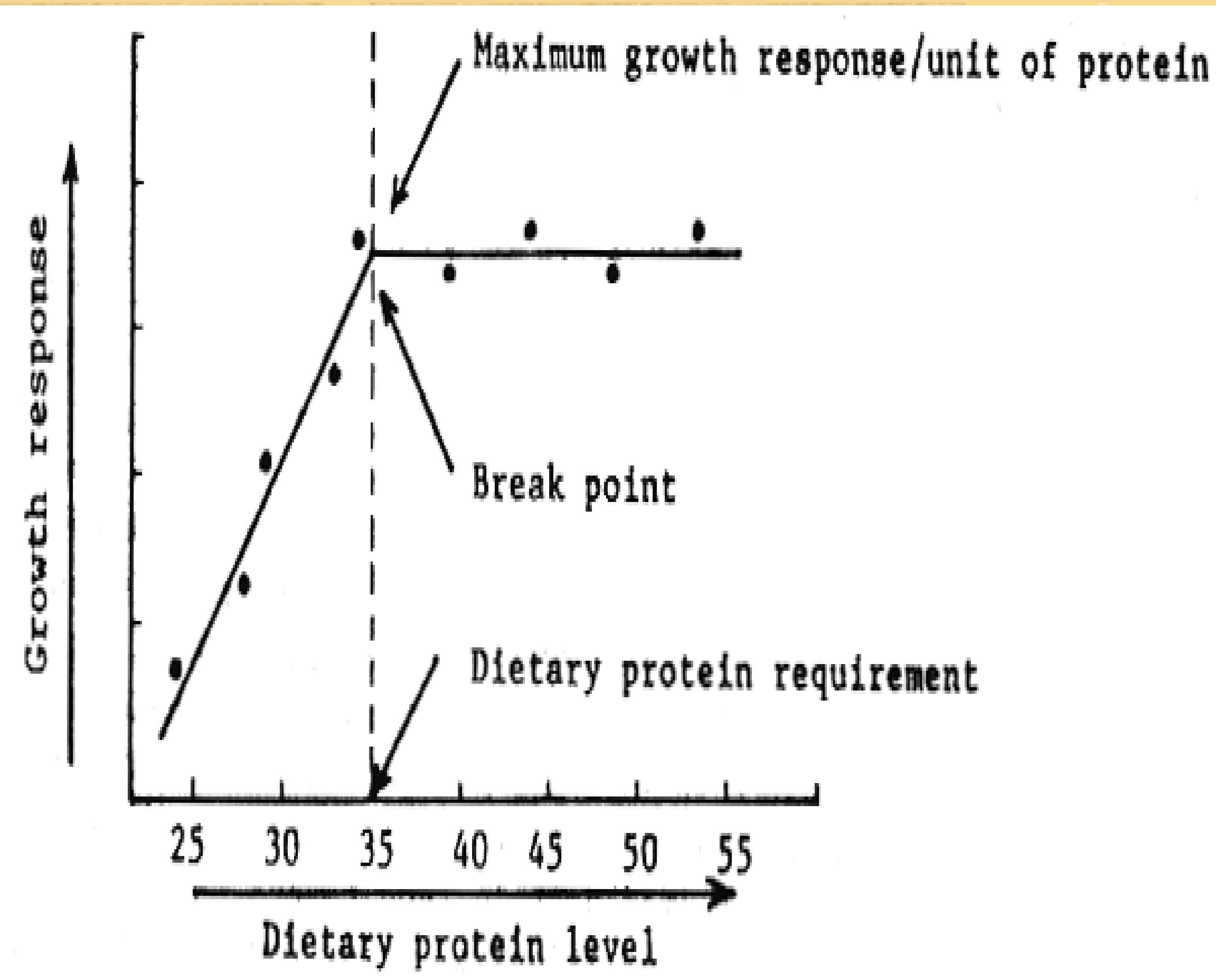
كثافة عالية

بيئة مسيطر عليها

بدون غذاء طبيعي

Optimum dietary protein level

Based on feeding techniques pioneered and developed for terrestrial animals the dietary protein requirements of fish were first investigated in the Chinnok salmon (Oncorhynchus tshawytscha) by Delong, et al, (1958). Fish were fed a balanced diet containing graded levels of a high quality protein (casein:gelatin mixture supplemented with crystalline amino acids to simulate the amino acid profile of whole hen's egg protein) over a 10-week period and the observed protein level giving optimum growth was taken as the requirement (Fig. 2). Since these early studies the approach used by workers today has changed very little if at all, with the possible exception of the use by some researchers of maximum tissue protein retention or nitrogen balance in preference to weight gain as the criterion of requirement (Ogino, 1980). Dietary protein requirements are normally expressed in terms of a fixed dietary percentage or as a ratio of protein to dietary energy.



Maximum growth response/unit of protein
Growth response
Break point
Dietary protein requirement
25
30
35
40
45
50
55
Dietary protein level

محاضرة ٤

تقييم نوعية العلائق والبروتين

<u>Food conversion ratio (FCR)</u> Defined as the grams of feed consumed per gram of body weight gain.

$$FCR = \frac{\text{Food fed*}}{\text{Weight gain**}}$$

*** As fed basis ie. dry weight**

**** Wet or fresh weight gain**

معدل التحويل الغذائي = الغذاء المتناول / الزيادة الوزنية

<u>Growth rate (GR)</u> Defined as the Daily weight increase .

$$GR\ (gm/d) = \frac{\text{Final wt.} - \text{initial wt.}}{\text{period}}$$

معدل النمو =الوزن النهائي – الوزن الابتدائي / الفترة

<u>Specific growth rate (SGR)</u> The rate of growth of an animal is a fairly sensitive index of protein quality; under controlled conditions weight gain being proportional to the supply of essential amino acids. Daily SGR can be calculated by using the formula:

$$SGR = \frac{(\log_e \text{final body weight} - \log_e \text{initial body weight})}{\text{Time period (in days)}} \times 100$$

معدل النمو النوعي = (لوغاريتم الوزن النهائي – لوغاريتم الوزن الابتدائي / الفترة) x ١٠٠

معدل النمو النسبي = (الزيادة الوزنية / الوزن الابتدائي) x ١٠٠ (RGR)

Protein efficiency ratio (PER) Defined as the grams of weight gained per gram of protein consumed.

$$PER = \frac{\text{Weight gain*}}{\text{Protein consumed}}$$

* With this method no allowance is made for maintenance: ie. method assumes that all protein is used for growth.

نسبة كفاءة البروتين = الزيادة في الوزن / كمية البروتين المتناول

Apparent net protein utilization (Apparent NPU) Defined as the percentage of ingested protein which is deposited as tissue protein.

$$\text{Apparent NPU} = \frac{Pb - Pa}{Pi} \times 100$$

where Pb is the total body protein at the end of the feeding trial, Pa is the total body protein at the beginning of the feeding trial, and Pi is the amount of protein consumed over the feeding trial

استغلال البروتين الصافي الظاهري = (بروتين الجسم النهائي – بروتين الجسم الابتدائي / البروتين المتناول) x ١٠٠

These essential and non-essential amino acids are listed in below

Essential Amino Acids	Non-essential Amino Acids
Arginine	Adenosine
Histidine	Alanine
Isoleucine	Aspartic Acid
Leucine	Cystine
Lysine	Glutamic Acid
Methionine	Glycine
Phenylaline	Proline
Threonine	Serine
Trytophan	Tyrosine
Valine	----

Provided the correct ratio and amount of essential amino acids are provided, protein synthesis can occur and new tissue can be laid down. As amino acids cannot be stored, they must be present in the correct amounts. If one amino acid is limiting or the protein component of the diet is in excess, proteins may be used as an energy source for maintenance and movement. This process, known as deamination, is energy- expensive and also leads to increased nitrogen waste production which can have environmental consequences.

مقارنة احتياجات البروتين والطاقة المهضومة بين نوعين من الاسماك والحيوانات الاخرى

Species	Feed gain	Protein g/kg diet	DE g/kg diet	DE / Protein
Rainbow trout	1.5	350	3000	8.6
Catfish	1.8	300	3420	11.4
Broilers	2.5	200	2950	14.8
Swine	4.0	160	3300	20.6
Beef cattle	8.0	100	2500	25.0

Nonprotein nitrogenous constituents

Amino acids are important not only as building blocks of protein but as the primary constituents or nitrogen precursors for many nonprotein nitrogen containing compounds.

Some of the more biologically important nonprotein nitrogenous compounds that originate from amino acids.

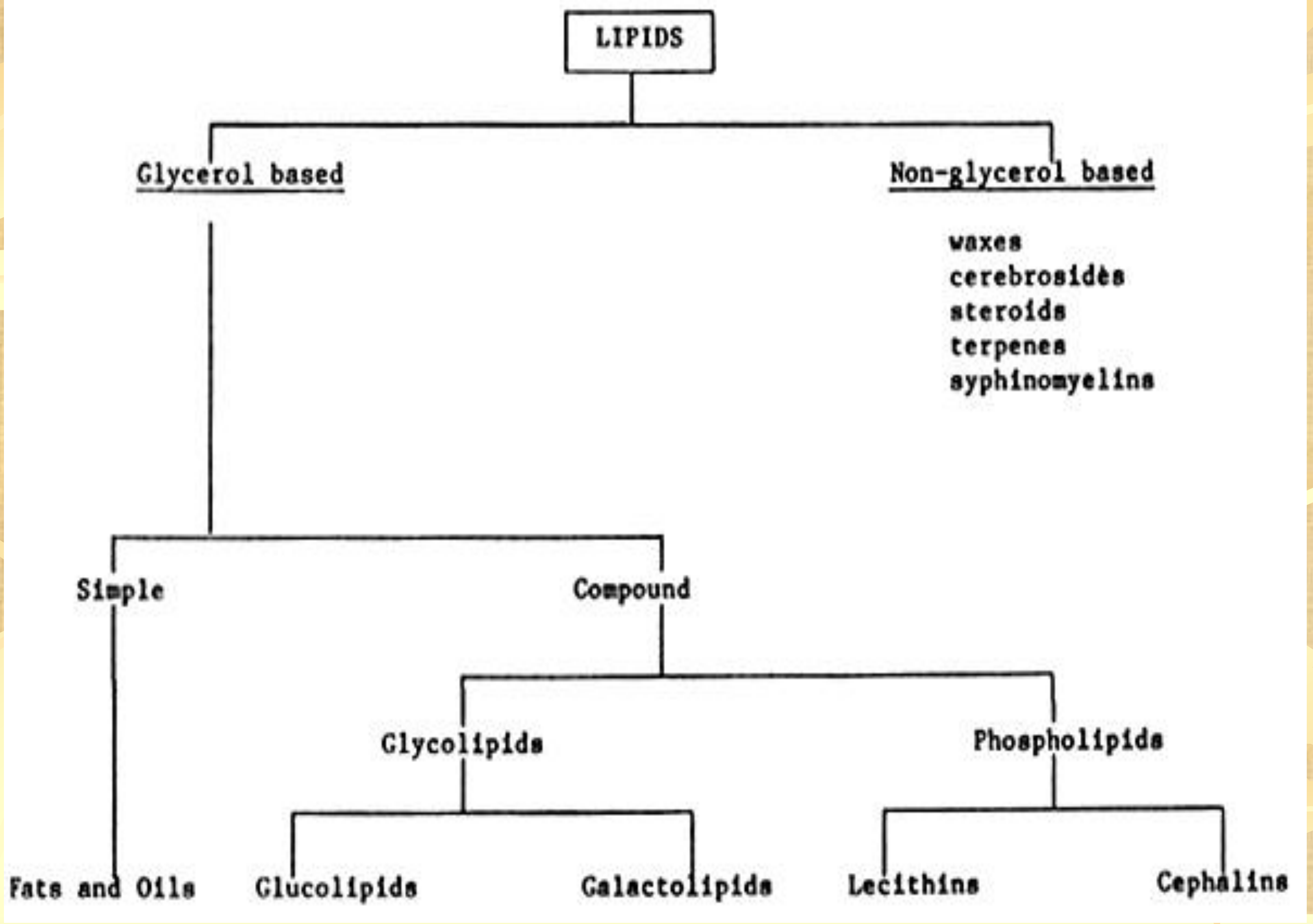
Nitrogenous compound	Amino acid precursor	Physiological function of compound
Purines & pyrimidines	Glycine & aspartic acid	Constituents of nucleotides and nucleic acids
Creatine	Glycine & arginine	Energy storage as creatine phosphate in muscle
Bile acids (glycoholic & taurocholic acids)	Glycine & cysteine	Bile acids, aid in fat digestion and absorption
Thyroxine, epinephrine & norepinephrine	Tyrosine	Hormones
Ethanolamine & choline	Serine	Constituents of phospholipids
Histamine	Histidine	A vasodepressor
Serotonin	Tryptophan	Transmission of nerve impulses
Porphyrins	Glycine	Constituents of haemoglobin and cytochromes
Niacin	Tryptophan	Vitamin
Melanin	Tyrosine	Pigment of skin and eyes

Lipids/fats

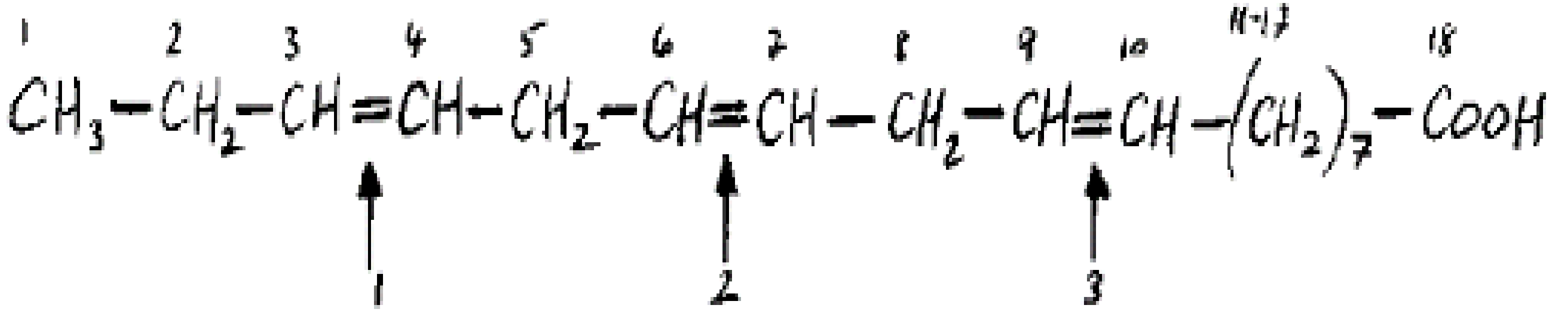
Of the major nutrients, lipids are the group most easily digested and metabolised. On a unit -for-unit basis they also provide more energy than carbohydrates or proteins. Fish also require certain essential fats for the correct structural arrangement of membranes such as cell walls - long-chain polyunsaturated fats are necessary for carnivorous fish, particularly salmonids. Over the years the fat/oil content of diets has steadily increased, from around 6% some 20 years ago, to 10 - 12% 15 years ago, 18 - 21% five or six years ago to current levels of 25 - 33%. These so-called 'high energy' diets have to be given with care as problems can and do occur.

Dietary lipids also serve as carriers for absorption of other nutrients including fat- soluble vitamins and pigments for flesh coloration in salmonids. As with protein, dietary lipids are provided from marine fish oils which are rich in essential fatty acids. Care has to be taken with regard to storage as PUFAs readily oxidise and become rancid.

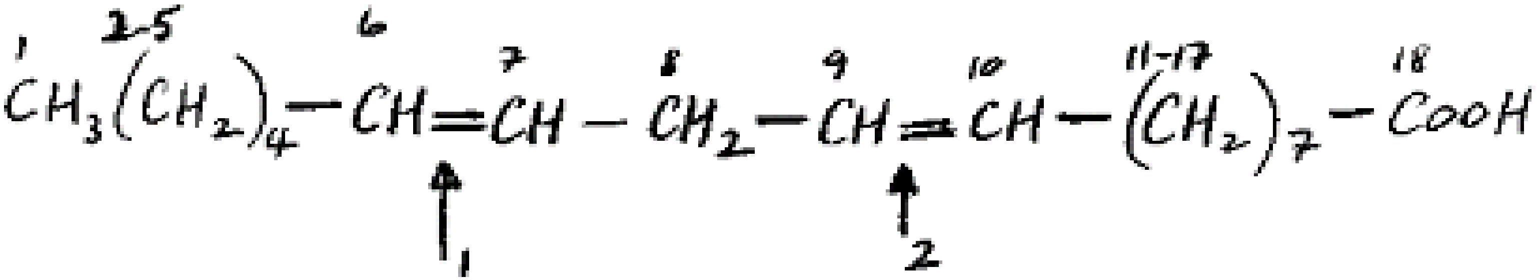
Lipids may be classified into two basic groups, according the presence or not of the alcohol glycerol



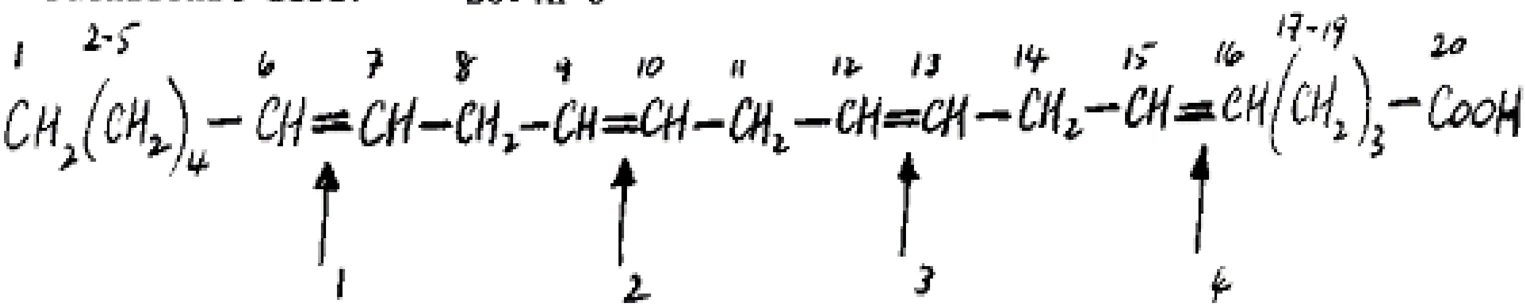
Linolenic acid: 18:3n-3



Linoleic acid: 18:2n-6



Arachidonic acid: 20:4n-6



Classification and naming of fatty acids, with selected examples. In the scientific designation, anoic refers to a fatty acid without double bonds in the carbon chain, enoic to a fatty acid with one double bond, dienoic to a fatty acid with two double bonds, trienoic to three, tetraenoic to four, etc. The shorthand notation gives the number of carbon atoms in the chain, the number of double bonds and the position of the first double bond counting from the methyl end of the fatty acid molecule. Unsaturated fatty acids of the n-3 and n-6 series are the indispensable (essential) fatty acids

Trivial name (scientific designation)	Number of carbon atoms	Number of double bonds	Fatty acid series	Shorthand notation
Saturated fatty acids (SFAs)				
Lauric (dodecanoic)	12	0		12:0
Palmitic (hexadecanoic)	16	0		16:0
Stearic (octadecanoic)	18	0		18:0
Monounsaturated fatty acids (MUFAs)				
Palmitoleic (hexadecenoic)	16	1	n-7	16:1 n-7
Oleic (octadecenoic)	18	1	n-9	18:1 n-9
Erucic (docosenoic)	22	1	n-9	22:1 n-9
Polyunsaturated fatty acids (PUFAs)				
Linoleic (octadecadienoic)	18	2	n-6	18:2 n-6
γ-Linolenic (octadecatrienoic)	18	3	n-6	18:3 n-6
α-Linolenic (octadecatrienoic)	18	3	n-3	18:3 n-3
Highly unsaturated fatty acids (HUFAs)				
Arachidonic (eicosatetraenoic)	20	4	n-6	20:4 n-6
EPA (eicosapentaenoic)	20	5	n-3	20:5 n-3
DHA (docosahexaenoic)	22	6	n-3	22:6 n-3

The essential fatty acid (EFA) requirements

a) **Aquatic animals** have a **higher** requirement for the **n-3 series** of fatty acids than **terrestrial animals**, for which the **n-6 series** is more **important**;
b) **EFA deficiencies** are more noticeable in **seawater** than in **freshwater** conditions (for trout). Thus **salinity affects EFA requirements**;
c) **Marine fish** appear to have a **greater** requirement for **HUFA's** than **freshwater** or **anadromous** species. It is **not yet known** whether they can utilize the **n-6** series as well as they can the **n-3** series;

d) **Coldwater** species appear to have a **greater** requirement for the **n-3 series** fatty acids than **warmwater** species;
e) **Shrimp** and prawns have a requirement for the **n-3 series** and the **n-3:n-6 ratio** is **important**;
f) The levels of either type of **PUFA's** can be detrimentally high in a feed. Knowledge of the specific requirements of a species is therefore constantly being sought to optimize formulation practice

g) Although many **vegetable** lipids (but not those of palm, olive or coconut) are **high** in **PUFA's**, the **best sources** (and the **most expensive**) sources of the **n-3 HUFA's** are **marine lipids**. **Vegetable** oils tend to have **high** levels of the **n-6 series** (**linoleic series**). **Beef** tallow have **low** total levels of **PUFA's**.

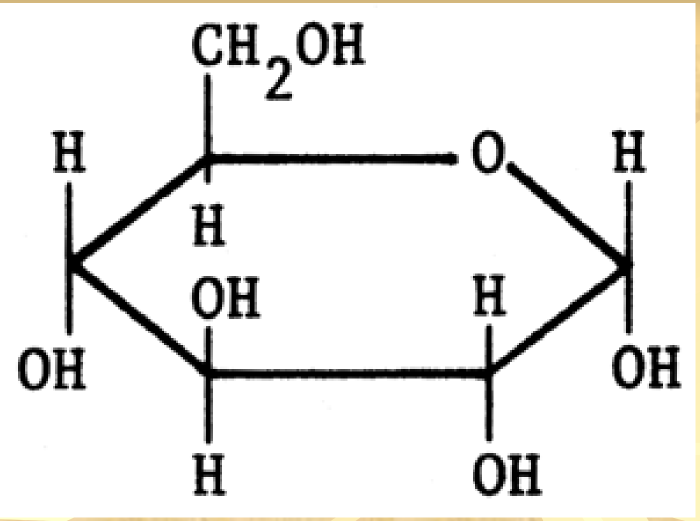
The necessity of high dietary levels of PUFA's in aquatic animal diets makes the possibility of fats becoming **rancid** very real. These may be **toxic** or **growth depressive**.

Carbohydrates

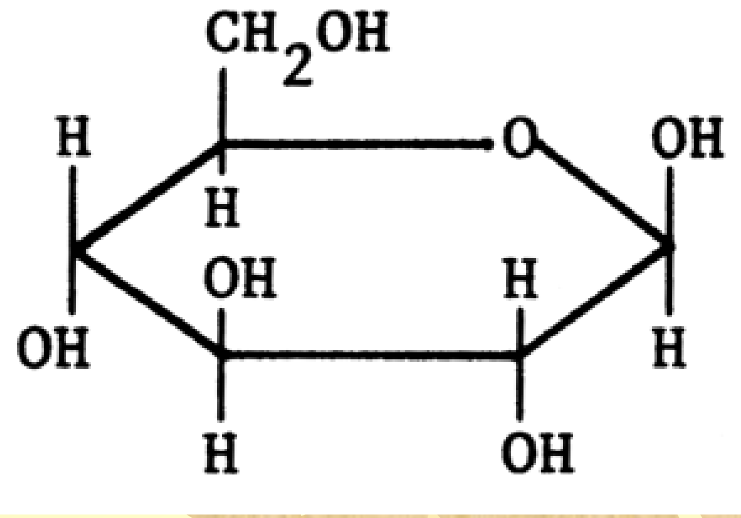
These act as a third source of dietary energy. In addition to being cheap they also act as binding agents for feed and increase the palatability of proprietary diets.

Carbohydrates are divided into two main groups - the sugars and the non-sugars. The former includes such things as glucose, sucrose and lactose whilst the latter contains the more complex materials such as starch and various polysaccharides. From a fish feed aspect, glucose and starch are of importance. As carnivorous fish, salmonids lack sufficient quantities of the enzymes necessary for efficient digestion and metabolism of most carbohydrates. Levels in proprietary diets are consequently low, carbohydrates giving way to increases in other components such as oil. For herbivorous fish, the carbohydrate content of man-made diets is correspondingly higher.

- SUGARS
  - Monosaccharides
    - Trioses
      - Glyceraldehyde
      - Dihydroxyacetone
    - Tetroses
      - Erythrose
    - Pentoses
      - Arabinose
      - Xylose
      - Ribose
    - Hexoses
      - Glucose
      - Galactose
      - Mannose
      - Fructose
  - Disaccharides
    - Sucrose
    - Lactose
    - Maltose
    - Cellobiose
    - Trehalose
  - Trisaccharides
    - Raffinose
  - Tetrasaccharides
    - Stachylose
- NON-SUGARS
  - Homopolysaccharides
    - Pentosans
      - Arabans
      - Xylans
    - Hexosans
      - Glucans
        - Starch
        - Dextrins
        - Glycogen
        - Cellulose
      - Fructans
        - Inulin
        - Levan
      - Galactans
      - Mannans
  - Heteropolysaccharides
    - Hemicelluloses
    - Gums
    - Mucilages
    - Pectic substances
    - Mucopolysaccharides



α-D-glucose



β-D-glucose

The biological importance of the structural difference between α and β -D-glucose must be stressed here; the structural configuration determining the physical and subsequent biological properties of polysaccharides composed of individual monosaccharide units. For example, the polysaccharide **cellulose** is composed of insoluble zig-zag chains of **β-glucose** units, whereas the polysaccharides **starch** and **glycogen** are composed of more biological reactive helical or branched chains of **α-glucose** units

Dietary carbohydrate utilization

The ability of **carnivorous** fish species to hydrolyze or digest complex carbohydrates is **limited** due to the weak **amylotic** activity in their digestive tract

Thus, for fish species such as trout, as the proportion of dietary starch is **increased**, starch digestibility **decreases** accordingly

in long term feeding trials with **carnivorous** fish species (i.e.. salmonids) it has been shown that high dietary carbohydrate levels **depress growth**, **elevate liver glycogen** levels, and cause eventual **mortality**

By contrast, **warmwater omnivorous** or **herbivorous** fish species such as carp (***C. carpio***), channel catfish (***I. punctatus***), tilapia (***O. niloticus***), and eel (***A. japonica***) have been found to be more **tolerant** of high dietary **carbohydrate** levels; the dietary carbohydrate being effectively utilized as a dietary **energy** source or excess stored in the form of body **lipid**

In fish and shrimp no absolute dietary requirement for carbohydrate has been established to date. This contrasts markedly with that of dietary protein and lipid, where specific dietary requirements have been established for certain essential amino acids and fatty acids. To a large extent this has been due:

1. **The carnivorous/omnivorous feeding habit of the majority of farmed fish and shrimp species.**
2. **The ability of fish and shrimp to synthesize carbohydrates (ie. glucose) from non-carbohydrate substrates such as protein and lipid (a process called gluconeogenesis).**
3. **The ability of fish and shrimp to satisfy their dietary energy requirements through protein and lipid catabolism alone if so required**

However, despite the apparent absence of a dietary requirement for carbohydrate in fish or shrimp, there is no doubt that carbohydrates perform many important biological functions within the animal body. For example; glucose, the end product of carbohydrate digestion in animals, serves as the major **energy source** of **brain** and **nervous** tissue, and as a **metabolic intermediate** for the **synthesis** of many biologically important compounds, including the **chitin exoskeleton** of **crustacean**, the **nucleic acids RNA and DNA**, and the **mucopolysaccharide** mucous secretions.

Although carbohydrates may be regarded as non-essential dietary nutrients for fish and shrimp, their **inclusion** in **practical diets** is warranted because:

1. They represent an inexpensive source of valuable dietary energy for noncarnivorous fish and shrimp species.
2. Their careful use in practical diets can spare the more valuable protein for growth instead of energy provision (a procedure called '**protein sparing**'.
3. They serve as essential dietary constituents for the manufacture of water stable diets when used as binders (i.e.. gelatinized starch, alginates, gums).
4. Certain carbohydrate sources serve as dietary components which can increase feed palatability and reduce the dust content of finished feeds (i.e.. cane or beet molasses).

Vitamins are defined as complex organic compounds required for normal metabolism, but

that cannot be synthesized by the animal . Some of the vitamins can be synthesized in small amounts by the microflora of the gastrointestinal tract. These compounds were initially termed vitamines, from ‘vital amines’, because it was thought that they contained amino-nitrogen. It is now known that only a few of them contain amino-nitrogen, but the amended group name vitamins is still used. The vitamins are a mixed group of compounds that are not closely related to each other chemically, and it has become practice to divide the vitamins into two groups on the basis of their solubility characteristics: lipid-soluble vitamins and water-soluble vitamins. The lipid-soluble vitamins are usually found, and extracted from feeds, in association with lipids. They are absorbed from the gastrointestinal tract along with lipids, are not normally excreted and tend to be stored in the body. In contrast, the water-soluble vitamins are not normally stored in the body in appreciable amounts, and any excess is excreted.

Eleven water-soluble and four lipid-soluble vitamins are known to be required by fish.
Eight of the water-soluble vitamins,
the B complex, have coenzyme functions and are required in small quantities.
The other water-soluble vitamins ascorbic acid (vitamin C), myo-inositol and choline are required in larger amounts, and these compounds are sometimes referred to as the macrovitamins.
The lipid-soluble vitamins are vitamins A, D, E and K. During the early years, the chemical structures of the
vitamins were unknown and they were assigned letters of the alphabet for convenience. Once vitamins had been isolated and their chemical structures determined, letters were sometimes replaced by names, e.g. thiamin (vitamin B1), riboflavin (vitamin B2), ascorbic acid (vitamin C) and biotin (vitamin H), based upon chemical structure, function or source.

Vitamins

Fish require a certain number of vitamins for good growth and health, the amount varying according to the age (and health) of the fish. They are all present in the dietary raw materials but processing and subsequent storage can result in variable levels being left when the time comes to feed the fish. As a result the raw material is assumed to contain no vitamins and sufficient amounts of synthetic vitamins are added during the manufacturing process.

Vitamins fall into two categories - water-soluble and fat-soluble. The former includes Vitamin C and various B vitamins (B1, B2, B6, B12) and the latter Vitamins A, D, E, and K. All these vitamins and several others are added to feeds in small amounts (e.g. 10-500 ug per kg dry weight of food).

Note: the fat-soluble vitamins can accumulate in fish and cause vitamin poisioning of hypervitaminosis. A lack of vitamins in the diet can lead to growth and health problems.

Water-soluble vitamins

Thiamine (vitamin B1)

Riboflavin (vitamin B2)

Pyridoxine (vitamin B6)

Pantothenic acid

Nicotinic acid (niacin)

Biotin

Folic acid

Cyanocobalamin (vitamin B12)

Inositol

Choline

Ascorbic acid (vitamin C)

Fat-soluble vitamins

Retinol (vitamin A)

Cholecalciferol (vitamin D3)

Tocopherol (vitamin E)

Phylloquinone (vitamin K)

Vitamins

Avitaminosis

Typical avitaminosis symptoms of Chastek-type paralysis, cataracts, convulsions, scoliosis, anemia, slime patch disease, clubbed gills, poor growth, anorexia, and increasing mortality were reported wherever fish were concentrated and intensive fish cultural practices were used. As diets became manufactured more from agricultural products, anemia and diet disease symptoms become more common, but specific cause-and-effect relationships were often difficult to define.

Hypervitaminosis

Hypervitaminosis D and A were reported when seal and whale liver were used as one of the fresh meat components in salmon diets . An analogy was drawn between symptoms observed in fish and those reported for other experimental animals, but no good experimental diets were available with positive experimental control over the particular vitamin that investigators wished to study.

Dietary vitamin requirements

Dietary vitamin requirements will depend upon a number of important factors:

1. The feeding behavior of the fish or shrimp species. Shrimp which consume their food slowly over a period of hours require higher dietary vitamin levels so as to counteract the progressive loss of water-soluble vitamins through leaching.
2. The vitamin synthesizing capacity of the gut microflora. Gut microflora is capable of synthesizing most B vitamins, pantothenic acid, biotin, choline, inositol and vitamin K, which in turn may become available to the animal, thereby reducing the dietary requirement. This may be particularly true for pond reared herbivorous or omnivorous fish and shrimp species.
3. The intended culture system to be used (ie. intensive, semi-intensive or extensive) and availability of natural food organisms within the water body.No beneficial effect of dietary vitamin supplementation was observed with fish either in fertilized ponds or cages (within the pond) at stocking densities of 2/m2 and 100/m3 respectively . Here, the important factor is the natural fertility of the water body and the total biomass of the fish or shrimp species stocked; the importance of dietary vitamin supplementation increasing with increasing stocking density and decreasing natural food availability per animal stocked. Natural pond food organisms therefore represent a potential source of dietary vitamins for pond cultured aquaculture species.

4. The size and growth rate of the fish or shrimp species cultured (i.e.. daily vitamin requirement per unit of body weight decreasing with increasing animal size and decreasing growth rate).
5. The nutrient content of the diet used. For example, the dietary requirement for tocopherol, thiamine and pyridoxine has been shown to increase with increasing dietary concentrations of polyunsaturated fatty acids, carbohydrate and protein, respectively.
6. The manufacturing process to be used for the production of the ration. For example, so as to counteract the destruction of the heat labile vitamins during feed manufacture, dry heat or steam pelleted feeds require higher dietary vitamin fortification than cold or wet pelleting processes.
7. The physico -chemical characteristics of the water body and physiological condition of the fish or shrimp species cultured. For example, the negative effects of pollution, disease, body wounds, and stress on fish have been found to be reduced in-part by dietary supplementation with ascorbic acid over and above that normally required by a healthy ‘non-stressed’ animal

Minerals

Fish require a supply of essential minerals for healthy growth. In the wild these are obtained from the surrounding water and the tissues of prey items. The main ones are calcium and phosphorus which are added to diets in the form of carbonates and phosphates. As synthetic minerals are much cheaper to produce than vitamins and are much more stable, mineral additives do not contribute greatly to higher feed costs. Other minerals required include iron, magnesium, manganese, sodium, potassium and cobalt.

The general function of minerals and trace elements can be summarized as follows:

- Minerals are essential constituents of skeletal structures such as bones and teeth.
- Minerals play a key role in the maintenance of osmotic pressure, and thus regulate the exchange of water and solutes within the animal body.
- Minerals serve as structural constituents of soft tissues.
- Minerals are essential for the transmission of nerve impulses and muscle contraction.
- Minerals play a vital role in the acid-base equilibrium of the body, and thus regulate the pH of the blood and other body fluids.
- Minerals serve as essential components of many enzymes, vitamins, hormones, and respiratory pigments, or as cofactors in metabolism, catalysts and enzyme activators.

Minerals

The elements required for the metabolic processes in fish can be classified into three groups:

(a) Constructional: Calcium, phosphorus, fluorine and magnesium are all important for the construction of the bones; sodium and chlorine are the main electrolytes of blood plasma and the extracellular fluid, while sulphur, potassium and phosphorus are the main electrolytes of the intracellular fluid. These elements are necessary, therefore, for the production of the above mentioned tissues.

(b) Respiratory: Iron and copper are important elements in haemoglobin and, therefore, also in the transfer of oxygen in blood.

(c) Metabolic: Many mineral elements, including some of those already mentioned above, take part in the metabolic processes. Usually they are required in much smaller amounts than for the previous two functions, and some only in trace quantities.

Difficulties in Studying Mineral Requirements of Fish

Inorganic elements are difficult to study, particularly trace elements.

1- The exchange of ions from the aquatic environment across gills and skin of fish complicates the determination of the quantitative dietary requirements.

2- Many trace elements are required in such small amounts that it is difficult to formulate purified diets low in mineral and maintain water sufficiently free of the test element.

3- Despite advances in instrumental analysis of trace elements making lower detection limits possible, there are still many problems associated with their accurate measurement in fish tissue to be overcome.

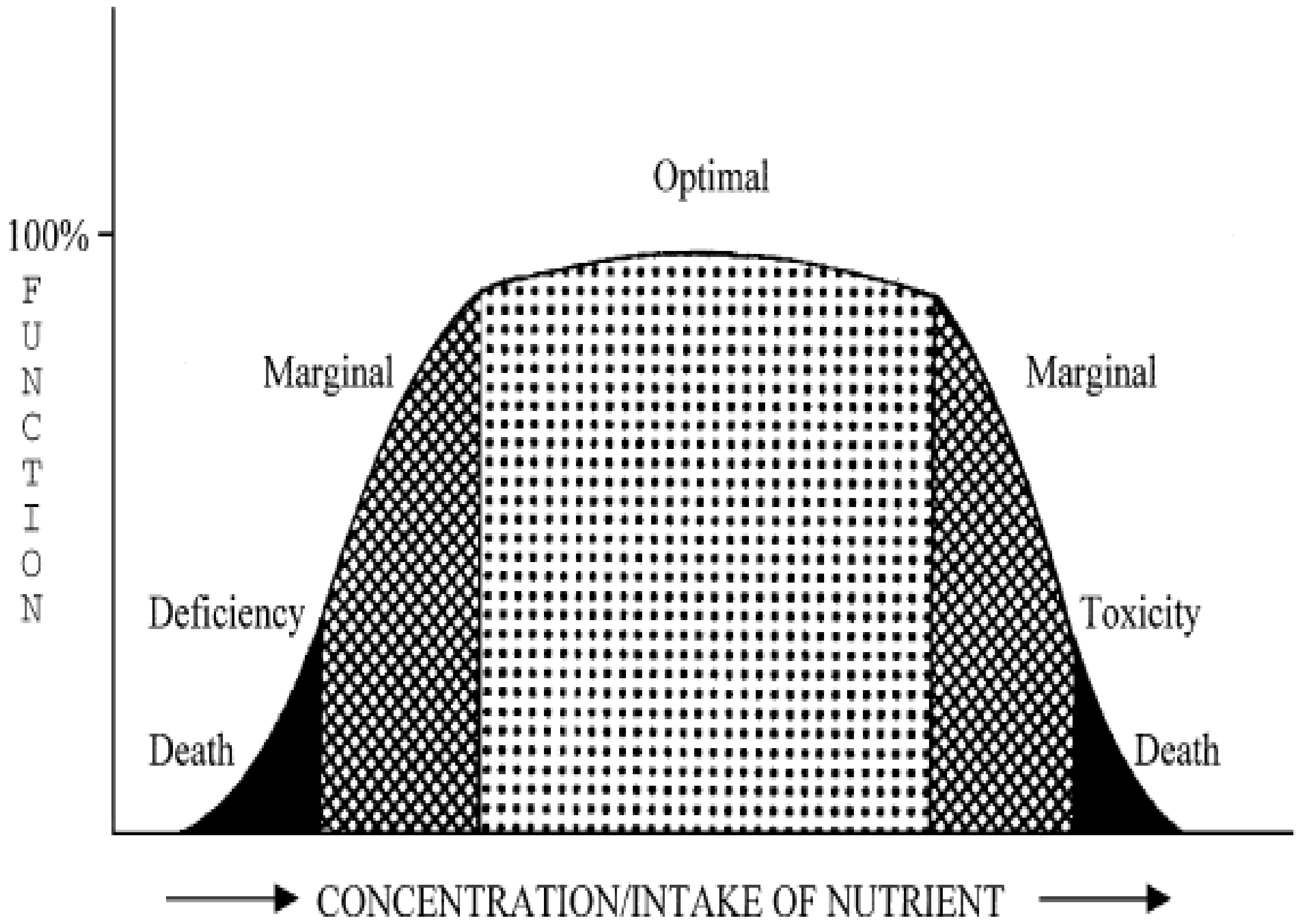
4-A critical factor in the determination of ultratrace elements, such as manganese, vanadium, and chromium, is the need for meticulous sample preparation.

5-Techniques that involve the use of high purity reagents, acid-cleaned glassware, and clean-room facilities should be employed to avoid contamination.

6-Often normal values of trace elements in fish tissue vary widely in reports from laboratory to laboratory.

7-The use of certified reference materials (CRM) is also essential to assure differences arise from the fish tissues being examined, and not the analytical techniques employed.

Fig.1: Biological dose–response curve.
Dependence of animal function on intake of an essential nutrient



the dietary requirement of a fish species for a particular element will depend to a large extent upon the concentration of that element in the water body. At present there is little information concerning the contribution of waterborne elements to the total mineral balance of fish

Element/species	Deficiency signs [1]
PHOSPHORUS	
Common carp (C. carpio)	Reduced growth, poor feed efficiency (1,2); bone demineralization, skeletal deformity, abnormal calcification of ribs and soft rays of pectoral fin (1); cranial deformity (1,3); increased visceral fat (4)
CALCIUM	
Channel catfish (I. punctatus)	Reduced growth, low carcass ash, Ca and P content (fed vitamin D deficienct diets, 6)
MAGNESIUM	
Common carp (C. carpio)	Reduced growth (11, 18); sluggishness, anorexia, convulsions, high mortality (11); cataracts (18)
IRON	Hypochromic microcytic anaemia (C. carpio - 26; C. major - 27; Salvelinus fontinalis - 28; A. japonica - 20; I. punctatus - 42; reduced growth and feed efficiency (42)
ZINC	
Common carp (C. carpio)	Reduced growth (18, 30); cataracts (18); anorexia, high mortality, erosion of fins and skin, elevated tissue concentrations of Fe and Cu in intestine and hepatopancreas (30)
MANGANESE	
Common carp (C. carpio)	Reduced growth (34, 18); short body dwarfism, cataracts (18)
COPPER	
Common carp (C. carpio)	Reduced growth (34, 18); cataracts (18)
SELENIUM	
Common carp (C. carpio)	Reduced growth (18, 37); cataracts (18); anaemia (37)
IODINE	
Salmonids	Thyroid hyperplasia/goitre (39, 40)