MSCZO-606

Fish and Fisheries
(Structure and Functions)
M.Sc. IV Semester

DEPARTMENT OF ZOOLOGY SCHOOL OF SCIENCES UTTARAKHAND OPEN UNIVERSITY

Fish and Fisheries (Structure and Functions)

(MSCZO-606)

DEPARTMENT OF ZOOLOGY
SCHOOL OF SCIENCES
UTTARAKHANDOPENUNIVERSITY
Phone No. 05946-261122, 261123

TollfreeNo.18001804025

FaxNo.05946-264232,
E.mailinfo@uou.ac.inhtpp://uou.ac.in

MEMBER OF THE BOARD OF STUDIES & PROGRAMME COORDINATOR

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Zoology, School of
Sciences
IGNOU Maidan Garhi,New Delhi

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Srinagar Garhwal

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DepartmentofZoolog
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KumaunUniversityNainital

Dr. Shyam S. Kunjwal
Assistant Professor
Department of Zoology,
Uttarakhand Open
University Haldwani,
Nainital.

Dr. Mukta Joshi
Assistant Professor
Department of
Zoology,
Uttarakhand Open University
Haldwani, Nainital.

PROGRAMMECOORDINATOR

Dr.PraveshKumarSehgal
Associate Professor
DepartmentofZoology, School of
Sciences, Uttarakhand Open
University
Haldwani, Nainital

EDITOR

Dr. Shyam S. Kunjwal
Assistant Professor
Department of Zoology,
UttarakhandOpenUniversity Haldwani, Nainital

UNIT WRITERS

Dr.Preeti Handa Kakkar (Unit1, 5, 6)
Associate Professor
Uttaranchal College of Science and Technology Dehradun
Dr.Beena Joshi Bhatt (Unit2, 11, 12, 13)
Associate Professor
Dolphin P.G. Institute of Biomedical and Natural Sciences Dehradun
Dr. Mukta Joshi (Unit 3, 4)
Assistant Professor
Department of Zoology,
Uttarakhand Open University Haldwani,
Nainital
Dr.Jaya Upreti (Unit7, 8, 9, 10)
Assistant Professor
Department of Zoology,
UttarakhandOpenUniversity Haldwani,
Nainital

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UNIT 1 CLASSIFICATION AND EVOLUTIONARY TREND

Contents

1.1 OBJECTIVES

- To gain knowledge about classification and evolutionary trend in fishes.
- To understand about classification and its importance.
- To know basic characteristics of fishes that make them diversified
- To learn about earlier fish classification
- To learn about recent classification of fishes.
- To understand about importance of fish habit and habitat
- To know about fish distribution pattern

1.2 INTRODUCTION

Aristotle is known as Father of Zoology, The study of fishes is known as **Ichthyology**.**Peter Artidi** is known as Father of Ichthyology. **Carolus Von Linnae** (1707-1778) is known as Father of Taxonomy. **Systematics**: is the study of biological diversity, it includes reconstructing the phylogenetic (genealogical) relationships of organisms.

Taxonomy: deals with describing and arranging biodiversity into a system of classification, and devising identification keys based on everything known about a particular class of objects. Thus taxonomy is a part of systematics that deal with the theory and practice of describing diversity and erecting classifications.

- Taxonomic characters can be meristic (countable), morphometric (measurable), morphological (including color), cytological, behavioral, electrophoretic, or molecular (nuclear or mitochondrial).
- The fundamental units of classification are species.
- In biology classification is used for identifying and making natural groups.
- The specimen or a group of similar specimens are compared with descriptions of what is already known.
- Classification provides the most characteristics useful in identification and place an organism into an already existing group or to create a new group for it, based on its resemblances to and differences from known forms.

Classification: the arranging of items into groups or categories. Classification of a group of organisms is done with an objective to reflect the evolutionary relationships of the various taxa in a hierarchical system of named groups.

A **fish** is cold blooded i.e. poikilothermic water dwelling vertebrate having gills and fins. They have high economic and food value.

General characteristics of fishes:

i. Fishes differ from each other in shape, size, habits and habitats.
ii. Fishes can live in all the rivers, seas, oceans, lakes, reservoirs, canals, tanks, ponds etc, either freshwater or marine.
iii. Fishes have streamlined body differentiated into head, trunk and tail and use fins for locomotion.
iv. Body covered by scales, denticles or bony plates (in Placodermi), Placoid scales in Chondrichthyes and ganoid, cycloid or ctenoid in Osteichthyes.
v. Cartilaginous or bony endoskeleton is cartilaginous or bony. Presence of well-developed skull.
vi. Gills used for respiration. Have 5-7 pairs of Gill-slits, naked or covered by an operculum.
vii. Poikilothermic.
viii. Heart is venous and two chambered, i.e., one auricle and one ventricle.
ix. Ureotelic excretions and Kidneys mesonephros.
x. 10 pairs of Cranial nerves.
xi. Paired nostrils.
xii. Well-developed lateral line system.
xiii. Sexes are separate.
xiv. Fertilization is internal or external.

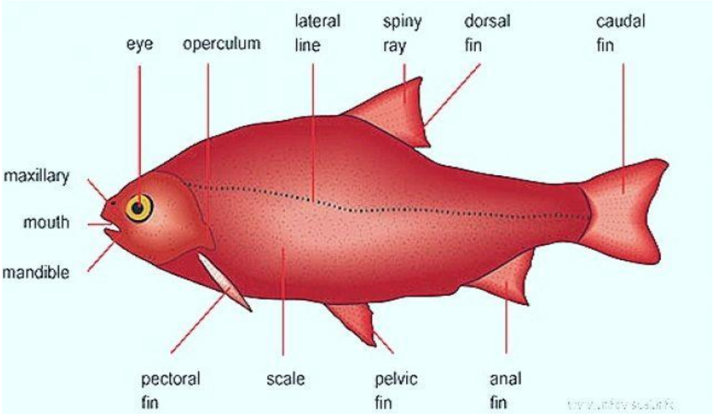


Fig 1.1 General characteristics of fish

Fishes arose and began to radiate more than 500 million years ago and exhibit diversity in their morphology, in the habitats they occupy, in their physiology, and in their behaviour. This diversity helps to understanding their evolutionary history and establishing a classification. From hagfishes and lampreys to sharks, lungfishes and flatfishes, fishes include a vast array of amazing adaptations to almost all aquatic environments on earth. Fossils are important in understanding evolutionary relationships.

Fishes represent 40 % of total vertebrates with about 36,000 species. Have evolved during Ordovician period. Ostracoderms are the first fossil records found in the rocks of Ordovician period, they were related to Cyclostomes with small jawless, bony, fishlike forms.

During early Cambrian the first fishes to fossilize occurred and lived into the Devonian. They lacked jaws.

During Devonian period the first jawed fishes, the Placoderms evolved. Also called the "the golden age of fishes".

Acanthodians or spiny sharks (unrelated to modern sharks) were the first advanced jawed fishes. They share a common ancestry with modern bony fishes, and they are often placed with sarcopterygians and actinopterygians in the grade Teleostomi.

Different system of fish classification are proposed from time to time when new fossil and living fishes are found due to diversity in their habits and habitat, anatomy, morphology, behaviour, reproduction modes, ecology, karyology etc.

1.1) CLASSIFICATION OF FISHES UPTO ORDER LEVEL

1. Cuvier first observed close resemblance of the scales of fossils and living fishes and classified fishes on basis of external and internal characterstics.

According to him

Fishes

Poisons Osseusx (= Bony fishes) — Cartilaginoux or Chondropterygiens (=cartilaginous fishes)

2. Agassiz considered the structure of scales as the basis for an ichthyological system and distinguished 4 orders as:

i. PLACOIDs- rays, sharks and cyclostome.
ii. GANOIDS-fossil Lepidoides and Coelacanthi and living Polypterus, Lepidosteus, Acipenser etc.
iii. CTENOIDS-Pleuronectidae, percidae, sciaenidae etc.
iv. CYCLOIDS –Clupeidae, Cyprinidae, Mugilidae etc.

3. Linnaeus in his publication Systema Naturae reported about classification and genera of fishes.

He classified fishes based on their character into

i. Pisces Apodes
ii. Pisces Jugulares
iii. Pisces Thoracici
iv. Pisces abdominals

4. Muller's Classification

Johannes Muller (1844) gave first classification of the lower vertebrates and divided Pisces into six subclasses. He recognized anatomical peculiarities of living type's .He reviewed the sharks and rays and grouping of bony fishes.

Muller classified fishes into six (6) sub-classes

Class: **Pisces**

Subclasses:

i. Dipnoi (Lung fishes)
   Order - Sirenoidei
ii. Teleostei (Bony fishes)
   Order - Acanthopteri
   - Acanthini
   - Pharyngognathi
   - Physostomi
   - Plectognathi
   - Lophobranchii
iii. Ganoidei (Polypterus, Amia, Lepidos)

Order - Holostei

Chondrostei

iv. Elasmobranchi (Sharks, Rays, & Rat fishes)

Order - Plagiostomi

Holocephali

v. Marsipobranchii (Cyclostomes)

Order - Hperoartii

Hyperotreti

vi. Leptocardii (Amphioxux)

Order - Amphioxini

1.) Jordan classification

Fishes: 6 classes

i. Leptocardii
ii. Marsipobranchii
iii. Ostracophori
iv. Arthrodire
v. Elasmobranchii
vi. Pisces

2.) Berg's Classification (1940)

L. S. Berg classified fishes into seven (7) classes; he included recent and fossil fishes.

Series: Pisces

Classes 7

i. Pterichthys
ii. Coccostei — extinct fishes
iii. Acanthodii
iv. Elasmobranchii
v. Holocephali
vi. Dipnoi
vii. Teleostomi

Teleostomi is further divided into 2 subclasses:

a) Crossopterygii

b) Actinopterygii

3.) A.S.ROMER CLASSIFICATION (1971)

S. Romer (1971) arranged fishes into four classes under super-class pisces.

Super-class: Pisces

A. **Class Agnatha (**Jawless vertebrates)

2 Subclasses:

I. Sub class Monorhina

Order

i. Osteostraci (extinct)

ii. Anaspida (extinct)

iii. Cyclostomata(living)

II. Sub class Diplorhina

Order

i. Heteorstraci (extinct)

ii. Coelolepida (extinct)

B. **Placodermii (**armoured or plate skinned fishes)

Orders:

i. Petalichthyida

ii. Rhenanida

iii. Arthrodira

iv. Phyllolepida

v. Ptyctodontida

vi. Antiarchi

C. **Chondrichthyes** (Cartilagenous fishes)

2Subclasses

i. Elasmobranchi

ii. Holocephali

D. **Osteichthyes** (Bony Fishes)

5 Subclasses

i. Acanthodi
ii. Actinopterygii
iii. Sarcopterygii
iv. Crossopterygii
v. Dipnoi

4.) Parker & Haswell's classification (1967)

Series PISCES

i. Class **Placodermi** (6 Subclasses

ii. Class **Chondrichthys**

Subclass Selachi (Sharks and Rays)

Subclass Bradyodonti (=Holocephali) *(Chimaera)*

iii. Class **Osteichthys**

Subclass Crossopterygii *(Latimeria)*

Subclass Actinopterygii (Rayfin bony fishes)

iv. Class **Dipnoi** (= Choanichthyes**)** (Lung fishes)

5.) Nelson's Classification (1994)

J. S. Nelson (1994) presented the classification of fishes in particular and chordata in general in a linear order which reflects their postulated evolutionary relationship (cladistic approach).

Fishes belong to Phylum **CHORDATA o**f Animal kingdom.

Characterstics of chordarta

i. Notochord or chorda dorsals present at the back.
ii. Nerve cord present.
iii. Pharyngeal gill slits or clefts or pouches present'

Phylum **CHORDATA** is divided into two groups

A) **Group ACRANIA or PROTOCHORDATA**

(Lower chordata):

- Absence of head, skull or cranium, vertebral column, jaws and brain.

I. **Sub Phylum – UROCHORDATA**

(Notochord present in the tail of tadpole like larvae)

II. **Sub phylum CEPHALOCHORDATA**

(Presence of notochord and nerve cord throughout life)

B) **Group CRANIATA or EUCHORDATA**

(Higher Chordata)

Presence of head with brain protected inside skull or cranium, vertebral column present.

I. **Sub Phylum Vertebrata**

(Vertebral column replaces notochord. Body divided into neck, trunk and tail)

Sub phylum vertebrata is further divided into two super classes based on presence and absence of jaws

1. Super class **AGNATHA**(Cyclostomata or Marsipobranchii)

   Characters - true jaws are absent, notochord present in adult

   Divided into two classes-

   a) CEPHALASPIDOMORPHA

   Examples – Cephalaspis, Drepanaspis, Thelodus (all extinct)

   Ichthyomyzon, Petromyzon, Lampetra, Eptratretus (living lampreys)

   Mayomyzon(fossil lamprey)

   b) Pteraspidomorpha.

   Example – Astraspis,Pteraspis.(all extinct)

   Myxine,Notomyxine, Neomyxine(all living form)

2. Superclass **GNATHOSTOMATA** –

   Characters - Presence of true jaws.

   Notochord is persistence or replaced by vertebral column

   Paired appendages (fins) are present.

Further Gnathostomes "Jawed Vertebtrates" are broadly of two types

It is divided into 2 grade

a. **PISCES** :

Large group of streamlined (freshwater and marine) fishes having different shapes, dimensions and colour,locomote using fins ,respire by gills.

Divided into 4 classes

i. Placodermii (extinct)
ii. Chondrichthyes
iii. Acanthodii (extinct)
iv. Osteichthyes

b. **TETRAPODA**: vertebrates having two pairs of limbs for movement and lungs for respiration in the adulthood.

Divided into 4 classes

i. Amphibian
ii. Reptilia
iii. Aves
iv. Mammalia

6.) The classification derived primarily from the works of ichthyologists C. Patterson, R. Miles, P.H. Greenwood, and K.S. Thomson, D.E. Rosen, G.D. Johnson, J.S. Nelson. (1984)

Fishes are divided into three groups:

1. **Superclass AGNATHA (jawless fishes)**

2. **Class CHONDRICHTHYES (cartilaginous fishes), and**

3. **Superclass OSTEICHTHYES (bony fishes).**

The latter two groups are included within the infraphylum Gnathostomata(jawed vertebrates).

1. **<u>SUPERCLASS AGNATHA</u>** (jawless fishes)
    - Vertebrates without true jaws
    - Paired fins are absent
    - Pectoral fin(1present
    - Pelvic fin not present
    - Notochord present
    - Gill pouches are present
    - Bony skeleton when present formed in skin
    - Sectorial or filter feeding mouth
    - 2 semicircular canals

The Agnatha include the modern day lampreys (Petromyzontiformes) and hagfish (Myxiniformes) and also includes several extinct orders.

Class Myxini

- **Order Myxiniformes**(hagfishes)
    - Absence of pectoral appendages
    - Poorly developed eyes
    - 1–16 pairs of external gill openings
    - Tail more or less diphycercal
    - Bottom-dwelling fishes
    - Presence of horny teeth

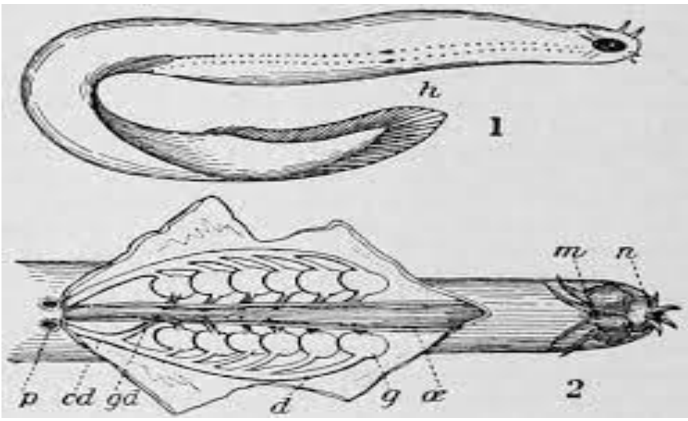


Fig 1.2 Hagfish

Class Cephalaspidomorphi (Monorhina)

- **Order Petromyzontiformes**(lampreys)
    - Absence of pectoral appendages
    - Lateral or dorsal eyes
    - 7 pairs of external gill openings;
    - Tail more or less diphycercal
    - Bottom dwelling fishes
    - Species are either parasitic or nonparasitic.

1. **<u>CLASS CHONDRICHTHYES</u> (OR SELACHII) (cartilaginous fishes)**

- Lacks true bone.
- Cartilaginous fishes
- Dorsal fin, fins, and fin spines rigid, not erectile, if present.
- Air bladder is absent
- Present only in marine water
- Ampulla of lorenzini present
- Caudal fin is heteocercal

Subclass Elasmobranchii(sharks and rays)

Chondrichthians with 5–7 pairs of gill clefts

- **Order Selachii** (sharks)-
    - Gill clefts opening at least partly on the side of the body
    - Heterocercal caudal fin

- **Order Batoidei** (rays, sawfishes, guitarfishes, skates, and stingrays)
    - 5 gill openings
    - Lack upper free eyelid

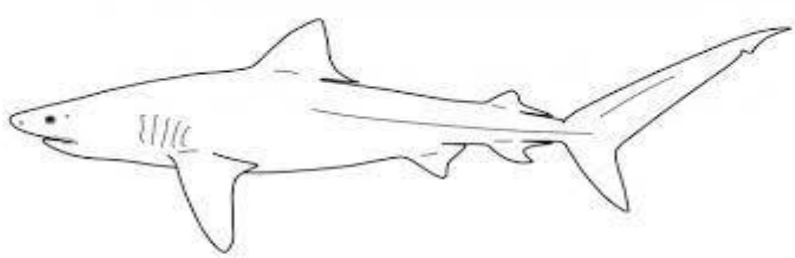


Fig 1.3 Shark

Subclass Holocephali

- Jaws are holostylic
- Internal skeleton of cartilage, dermal skeleton of dentine or dentinelikr tissue.
- Scales donot continue to grow once fully formed

➤ **Order Chimaeriformes** (chimaeras)

- Pelvic fin claspers present
- Dorsal fin spine present or absent
- Cephalic clasper present in some

2. **SUPERCLASS OSTEICHTHYES**(bony fishes)

- Bony skeleton and vertebrae present
- Have paired fins
- Jaws present
- Present in marine water, fresh water or brackish water

I. **Class Actinopterygii** (ray-finned fishes)

- Fins supported by rays of dermal bone
- Jawed fishes
- Well ossified skeleton
- Ganoid scales
- Single dorsal fin
- Scales grow throughout life
- Presence of swim bladder

Fig 1.4 Actinopterygii

Subclass Chondrostei

- **Order Acipenseriformes** (sturgeons and paddlefishes)
  - No internal ossification
  - Scales as large scutes
  - Snout large and tactile
  - Heterocercal tail
- **Order Polypteriformes** (bichirs and reedfish)
  - Ganoid scales
  - Fins modified into long continuous dorsal
  - Tail diphcercal

Infraclass Holostei

- Tail hemiheterocercal
- Spiracle lost
- Tinning scales and loss of ganoid layer
- Vertebral column tended to increasing ossification.

- **Order Amiiformes** (bowfins and fossil relatives)
- **Order Semionotiformes** (gar and fossil relatives)

Infraclass Teleostei(advanced bony fishes)

- Homocercal tail
- Scales when present are thin, overlapping plates of bone that continue to grow throughout life
- Lower jaw lack certain bones

Superorder Osteoglossomorpha

- **Order Osteoglossiformes**(bonytongues,freshwater butterfly fishes, mooneyes, knife fishes, mormyrs)

- Primitive jaw suspension and shoulder girdle.
- No leptocephalus larvae.
- Some with electricity-producing organ

Superorder Elopomorpha

- A diverse group including very primitive fishes and specialized fishes like eels
- Leptocephalus larva

- **Order Elopiformes** (tarpons and ten-pounders)
    - Body fusiform, typical fishlike shape
- **Order Albuliformes** (bonefishes, halosaurs, and deep-sea spiny eels)
    - Snout enlarged; mouth small and underslung;
- **Order Anguilliformes** (eels)
    - Body elongate
    - Fins reduced and gill chamber modified
    - Opercular apparatus reduced
    - Caudal and other fins often greatly reduced

Fig 1.5 Eel

- **Order Saccopharyngiformes** (gulper eels)
    - Elongated Jaws and hyomandibular
    - Caudal fin absent or rudimentary
    - Opercular bones absent
    - Branchiostegal rays, scales, pelvic fins or ribs.

Superorder Clupeomorpha

- Special type of ear–swim bladder connection present
- Head lateral line canals on operculum.

➢ **Order Clupeiformes** (herrings, anchovies, and allies)

Superorder Ostariophysi

Series Anotophysi

➢ **Order Gonorynchiformes** (milkfish, beaked sandfishes, snake mudheads, and relatives)

- Toothless
- Epibranchial organs present and a characteristic caudal skeleton.

Series Otophysi

- Presence of a Complex Weberian apparatus

➢ **Order Characiformes**

- Mouth not protractile
- Jaws toothed.

➢ **Order Cypriniformes** (carps and minnows)

- Pharyngeal teeth, mouth toothless, protractile.
- Adipose fin rarely present.

Fig 1.6 Carps

➢ **Order Siluriformes** (catfishes)

- Parietal, symplectic, suboperculum, and true scales absent
- Fusion of the supportive parts of the Weberian apparatus extensive

Fig 1.7 Catfish

- **Order Gymnotiformes** (knifefishes, gymnotid and electric eels)
  - Body elongated
  - Anal fin very long; electric organs present, some extraordinarily powerful.

Superorder Protacanthopterygii

- Adipose fin present
- Mesocoracoid bone usually present
- Glossohyal teeth usually prominent (lost in some)
- Upper jaw usually not protrusible

- **Order Esociformes** (pikes and pickerels)
  - No adipose fin
- **Order Osmeriformes** (argentines and smelts)
  - Adipose fin present in many forms.
- **Order Salmoniformes** (salmons, trouts, and allies)

Superorder Stenopterygii

- **Order Stomiiformes**
  - Adipose fin present or absent,
  - Swim bladder without duct or absent entirely
  - Anterior vertebrae sometimes unossified
  - Light organs present in most families
  - Members of some families with chin barbel
- **Order Ateleopodiformes** (highfin tadpole fish)
  - Snout bulbous, caudal fin reduced
  - Skeleton largely cartilaginous.

Superorder Cyclosquamata

- **Order Aulopiformes** (barracudinas, lizardfishes, greeneyes, pearleyes, and relatives)

Superorder Scopelomorpha

- **Order Myctophiformes** (lantern fishes)
    - Head and body compressed
    - Adipose fin present
    - Mouth usually large and terminal.

Superorder Lampridiomorpha

- **Order Lampriformes** (opahs, oarfishes, and relatives)
    - No subocular shelf and pelvic spine

Superorder Polymixiomorpha

- **Order Polymixiiformes** (barbudos or beardfishes)
    - Barbels suspended from the hypohyal bones (anterior part of the gill arches)
    - spines on the dorsal and anal fins

Superorder Paracanthopterygii

- Most with a distinctive type of jaw musculature

- **Order Percopsiformes** (trout-perches, pirate perches, and cave fishes)
    - Mouth gape and buccal dentition reduced
    - median fin spines reduced or lost

- **Order Gadiformes** (cods and allies)
    - Reduced caudal skeleton; elongate body; altered head and jaw structure.
    - very reduced fin spines.
    - Order includes cods, hakes, grenadiers, and rattails.

- **Order Batrachoidiformes** (toadfishes)
    - Bottom fishes with short, small, spinous dorsal fins; long soft-rayed dorsal fins; flat heads.

Fig 1.8 Toadfish

- **Order Lophiiformes** (goosefishes, anglerfishes, frogfishes, and batfishes)
  - Spinous dorsal fin modified as a movable lure.
  - Some deep-sea forms with light organs and males parasitic on females.

- **Order Ophidiiformes** (cusk eels, brotulas, and pearlfishes)
  - Pelvic fins, when present, anterior, with 1 or 2 soft rays in each fin,

Superorder Acanthopterygii (spiny-rayed fishes)

- Spiny fins present
- Protractile mouth
- Pectoral fin relatively higher on side of body;
- Baudelot's ligament almost always attached to basicranium.

Superorder Acanthopterygii has 13 orders that are divided into 3 categories (sometimes called series) on the basis of the number of vertebrae, the condition of the fin spines, the position of the pelvic fins, and the presence or absence of ctenoid scales.

a. The series Atherinomopha : 3 orders,
   The Atheriniformes (silversides and relatives)
   Cyprinodontiformes (killifishes and relatives), and
   Beloniformes (needlefishes and relatives).
b. The series Mugilomorpha: 1 order, Mugiliformes, the mullets.
c. The series Percomorpha: 9 acanthopterygian orders.

a. Series Atherinomorpha

- Testes are spermatogonial type
- Demersal egg with chorionic filaments
- Fin spines present or absent
- Vertebral number higher than 24
- Ctenoid scales rare
- Pelvic fins abdominal, subabdominal, or thoracic in position
- Pelvic fins may be connected to pleural rib via a ligament.

➢ **Order Atheriniformes**(silversides)

- Short preanal length of flexion larvae
- Pelvic medial plate not extended to anterior end
- 2nd dorsal-fin spine flexible.

➢ **Order Cyprinodontiformes** (killifishes and live-bearers)

- Symmetrical caudal skeleton with single epural mirroring autogenous parhypural.

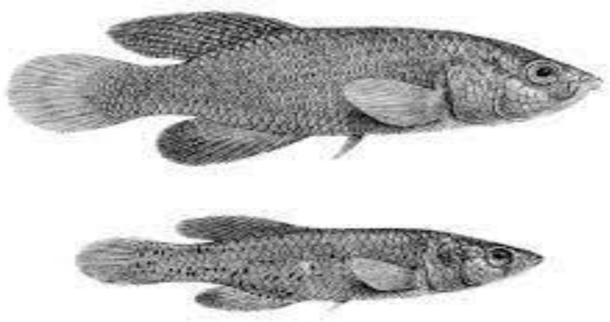


Fig 1.8 Spotted Killifish

➢ **Order Beloniformes** (medakas, needlefishes, halfbeaks, and allies)

- Absence of the interhyal bone
- Reduction or loss of the interarcual cartilage

b. Series Mugilomorpha

- Oral and branchial filter-feeding mechanism
- Intestines muscular and extremely long
- lateral line absent or highly reduced

- 2 dorsal fins, the 1st spinous
- pelvic fin with 1 spine and 5 rays
- ctenoid scales
- 24 to 26 vertebrae.

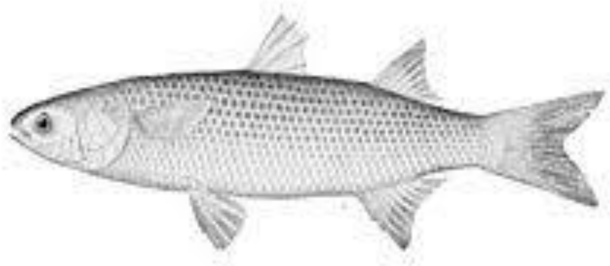


Fig 1.9 Mullet

➢ **Order Mugiliformes** (mullets)

c. **Series Percomorpha** (perches and perchlike fishes)

- Pelvic fin with 1 spine and 5 rays
- pelvic fin connected to postcleithrum or coracoid via a ligament
- ctenoid scales.

➢ **Order Stephanoberyciformes** (whale fishes, bigscale fishes, and allies)

- Body roundish
- Skull bones extremely thin
- Subocular shelf absent
- Supramaxilla reduced or absent
- Uniquely modified extrascapular bone.

➢ **Order Beryciformes** (squirrelfishes and several deep-sea fishes)

- Subocular shelf present or reduced
- orbitosphenoid present
- 5 or more soft rays in pelvic fins
- Jaukbowski's organ present

➢ **Order Zeiformes** (dories, boarfishes, and relatives)

- Anal fin with 1–4 spines

- Pelvic fin with 1 spine and 5–9 branched rays
- Caudal fin with less than 15 principal rays.

➢ **Order Gasterosteiformes** (sticklebacks, tubesnout fish, and seahorses)
- Frequently with strong spines in dorsal and pelvic fins
- Snout often elongated
- Body often with dermal plates.

➢ **Order Synbranchiformes** (swamp eels and spiny eels)
- Fins reduced
- Fin spines absent
- Pharynx modified for breathing air in swamp eels.

➢ **Order Scorpaeniformes** (scorpionfishes, sculpins, flying gurnards, and relatives)
- Distinctive caudal skeleton and a bony process connecting the 3rd orbital with the preoperculum.
- Some with external bony plates.

Fig 1.10 Flying Gurnard

➢ **Order Perciformes**
- Fins usually with spines
- Pelvic fin with 1 spine and not more than 5 rays, usually below pectoral fins
- Caudal fin with 15 rays

➢ **Order Pleuronectiformes** (flounders, soles, halibuts, and other flatfishes)
- Both eyes on same side of head
- Skull twisted and asymmetrical
- Fins usually without spines.

- **Order Tetraodontiformes** (pufferfishes)
  - With a beaklike snout
  - Gill opening restricted to a small opening.

II. **Class Sarcopterygii** (fleshy-finned fishes)

- Primitive members have heterocercal tail fin
- 2 dorsal fins present
- Cosmoid scales present
- Modern freshwater forms have lungs
- Scales grow throughout life of the individual.

Subclass Coelacanthimorpha (Crossopterygii)

- **Order Coelacanthiformes** (coelacanths and fossil relatives)
  - Cranium divided into 2 parts (anterior and posterior) at region for exit of the 5th cranial nerve (movable on each other)
  - Teeth labyrinthodont
  - Mostly marine, including theliving fossil, *Latimeria chalumnae,* from South Africa, and *L. menadoensis*, from Indonesia, both of which lack lungs.

Fig 1.11 :Latimeria chalumnae (coelacanth, a lobe-finned fish)

Subclass Dipnoi (lungfishes)

- Cranium not divided into movable parts
- teeth on upper jaw early, reduced and lost in later members

- **Order Ceratodontiformes**(Australian lungfishes)

- **Order Lepidosireniformes**(South American and African lungfishes)

Fig 1.12 Lungfish

7.) Latest classification according to Nelson

Chordates are part of super phylum DEUTEROSTOMIA

PHYLUM CHORDATA

A. Subphylum **UROCHORDATA** (tunicates or sea –squirts**)**
B. Subphylum **CEPHALOCHORDATA** (lancelets)
C. Subphylum **CRANIATA** (fishes, amphibians, reptiles, birds and mammals)

A. Subphylum UROCHORDATA (Tunicata: the tunicates)

- Their tadpole larvae possess gill slits
- Dorsal hollow nerve cord
- Notochord present
- A muscular, unsegmented tail
- The adults are usually sessile filter feeders

1.) Class ASCIDIACEA (ascidians)

- Larvae free-swimming, tadpolelike (short-lived and nonfeeding)
- Adults sesssile benthic, solitary or colonial, and without a tail.

2.) **Class THALIACEA** (salps)

- Larvae and adults transparent, pelagic
- Adults solitary or colonial.
- Sexual and asexual reproductive stages occurring.

i. **Order PYROSOMIDA**.

- Tubular colonies with a common atrial chamber.
- Emit a strong phosphorescent light.

ii. **Order DOLIOLIDA** (Cyclomyaria).

- Barrel-shaped with 8 or 9 muscle bands around the body.

iii. **Order SALPIDA** (Hemimyaria).

- Cylindrical or prism-shaped

3.) **Class APPENDICULARIA** (Larvacea)

- Larval characteristics (such as the tail) are retained in the adult.

B. SUBPHYLUM CEPHALOCHORDATA (Acrania, in part)

- The notochord extends to the anterior end of the body, anterior to the brain.
- Absence of cranium and vertebrae
- Heart consisting of a contractile vessel
- Liver as a gut diverticulum
- Epidermis as a single layer of cells
- Protonephridia with solenocytes for excretion
- True brain absent
- Sexes separate.
- Notochord is present.

- **Order AMPHIOXIFORMES** (lancelets).
  - Small , slender, fishlike animals
  - Spend most of their time buried in sand or coarse shell gravel
  - Feeding occurs by straining minute organisms from the water that is constantly drawn in through the mouth.

Fig 1.13 Lancelet

3. **SUPERPHYLUM CONODONTA** (conodonts)

Class CONODONTA

- Were diminutive , eel-like
- Varied shaped dental apparatus
- Scavenge on dead and dying animals
- Tooth like elements called conodonts
- Closely related to sub phylum Craniata

4. **SUBPHYLUM CRANIATA**

- Notochord doesnot extends in front of brain
- Cranium is present
- Vertebrae present
- Heart chambered
- Brain well developed; 10 to 12 pairs of cranial nerves
- Nephridia absent

- Endostyle only in larval lampreys (ammocoetes)

1.) INFRAPHYLUM MYXINOMORPHI

Class MYXINI

- **Order MYXINIFORMES** (Hyperotreti) (1)—hagfishes.
  - Presence of 1 semicircular canal (and one macula)
  - 1–16 pairs of external gill openings
  - Body naked, eel-like
  - Paired fins absent
  - In adults lateral-line system absent
  - Neuromasts absent.
  - Barbels present around biting mouth

Fig 1.14 Hagfish

2.) INFRAPHYLUM VERTEBRATA

I. SUPERCLASS PETROMYZONTOMORPHI

Class PETROMYZONTIDA

- **Order PETROMYZONTIFORMES** (Hyperoartii) (2)—lampreys.
  - 2 semicircular canals present
  - 7 pairs of external lateral gill openings
  - Eyes are well developed in adult
  - Single median nostril (nasohypophyseal) opening between eyes
  - Body naked, eel-like

- Absence of paired fins
- 1 or 2 dorsal fins present

- Tail diphycercal (isocercal) in adults, hypocercal in ammocoete larvae
- Barbels absent

Fig 1.15 Lamprey

II. SUPERCLASS PTERASPIDOMORPHI

Class PTERASPIDOMORPHI (Diplorhina)

- Oak leaf–shaped tubercles on dermal bone
- True bone cells absent
- 2 semi-circular canals.

i. Subclass ASTRASPIDA

- Thick, glassy enameloid caps on the tubercles
- Eyes small and laterally placed
- 8 gill openings with no cover
- Paired fins absent
- Tail covered with large diamond shaped scales.

➢ **Order ASTRASPIDIFORMES**.

ii. Subclass ARANDASPIDA

- Eyes in extreme anterior position, at tip of head

- Paired pineal and parapineal openings present
- 10 external branchial openings present
- Paired fins absent

➢ **Order ARANDASPIDIFORMES.**

iii. Subclass HETEROSTRACI

- Presence of pair of external lateral gill openings
- Body with large scales covering the trunk and tail
- Eyes lateral , small
- Sclerotic ring absent;
- Movable paired fins absent
- Anal fin absent
- Tail internally hypocercal, externally often symmetrical

➢ **Order CYATHASPIDIFORMES.**

- Ornamentation of longitudinal, dentine ridges
- Dorsal shield composed of a single plate.

➢ **Order PTERASPIDIFORMES.**

- Dorsal shield composed of several plates,
- Ornamented, except in psammostcids, with concentric dentine ridges.

III. SUPERCLASS ANASPIDOMORPHI

Class ANASPIDA

➢ **Order ANASPIDIFORMES** (Birkeniae).

- 6 to 15 or more pairs of external lateral gill openings
- Eyes large and lateral
- Tail hypocercal with large epichordal lobe
- Anterior dorsal fin absent
- Unique pectoral spines or rods present
- Anal fin reduced or absent

- Body usually covered with dorsoventrally elongated ornamented scales
- Body fusiform and somewhat compressed
- Mouth terminal

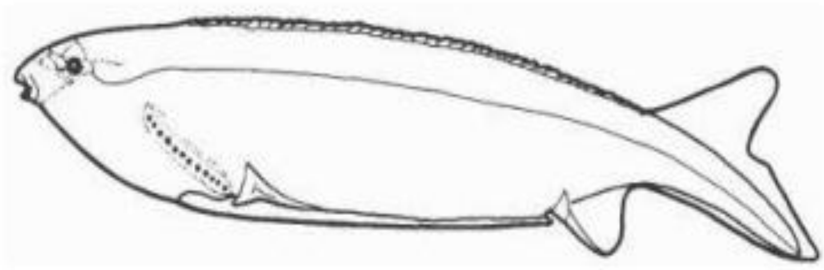


Fig 1.16 Birkenia

IV. SUPERCLASS THELODONTOMORPHI

Class THELODONTI

- Presence of isolated micromeric scales
- Most are depressed, with horizontal mouth
- Asymmetrical tails
- One dorsal fin and paired pectoral fin flaps

➢ **Order ARCHIPELEPIDIFORMES**.

- Are primitive
- Lack the solid, bony head shields

➢ **Order FURCACAUDIFORMES** (fork-tailed thelodonts).

- Body compressed
- Eyes lateral and large
- Barrel shaped stomach present
- Caudal fin with large dorsal and ventral lobes and scale covered
- Tapered fin supports.
- Lateral line branches on both lobes of the tail

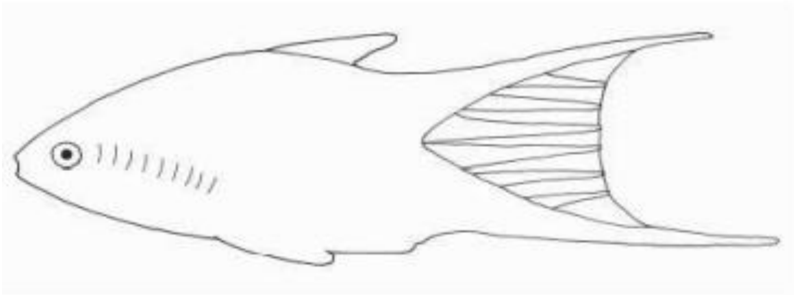


Fig 1.17 Fork- tailed thelodont

- **Order THELODONTIFORMES**
  - Depressed body form
  - 8 pairs of gills
  - Stomach present

V. SUPERCLASS OSTEOSTRACOMORPHI

Class CEPHALASPIDOMORPHI (Monorhina)

- Two semicircular canals
- Single dorsomedian nostril (nasohypophyseal) opening between eyes

- **Order CEPHALASPIDIFORMES** (Osteostraci).
  - Presence of 10 pairs of gill chambers and 10 pairs of external ventral gill openings
  - Dorsal eyes
  - Sclerotic ring present
  - Endolymphatic duct present
  - Head with complex, ornamented, polygonal interlocking plates
  - Body with dorsoventrally elongated ornamented scales
  - Anal fin absent

- **Order GALEASPIDIFORMES**.

- Large median dorsal opening in front of the eyes that connects with the paired nasal cavities and with the pharynx.
- Up to 45 pairs of gill compartments
- Lack a dorsal and paired fins
- Hypocercal tail.

- **Order PITURIASPIDIFORMES** (Pituriaspida)
  - Anteriorly projecting rostrum
  - Elongate bony armour covers the head and trunk
  - Dorsal nasohypophyseal opening absent

VI. SUPERCLASS GNATHOSTOMATA — JAWED VERTEBRATES

- Jaws present, derived from modified gill arches;
- Paired limbs(or fins) usually present
- Gills covered with ectoderm
- Gills opening to surface in fishes through slits
- 3 semicircular canals present

A.) **Grade PLACODERMIOMORPHI**

Class PLACODERMI

- Dermal bony plates on Head and shoulder girdle
- Gill chamber extending anteriorly under neurocranium and may be covered laterally by dermal bone
- Five gill arches
- Tail diphycercal or heterocercal
- Anal fin absent.

- **Order PSEUDOPETALICHTHYIFORMES**
  - Most primitive

- **Order ACANTHOTHORACIFORMES.**
  - One pectoral fin element

- **Order RHENANIFORMES.**
  - With a ray like body

- **Order ANTIARCHIFORMES** (antiarchs).
  - Pectoral fin a slender appendage covered by small dermal plates
  - Bottom feeders with mouth sub-terminal

- Eyes dorsal , pineal organ between eyes
- Sockets of the head-body joint on the head shield

- **Order PETALICHTHYIFORMES**

- **Order PTYCTODONTIFORMES**
    - Large sexually dimorphic pelvic fins
    - Claspers in males

- **Order ARTHRODIRIFORMES** (arthrodires).
    - Most arthrodires were probably nektonic predators

EUGNATHOSTOMATA (Unranked)

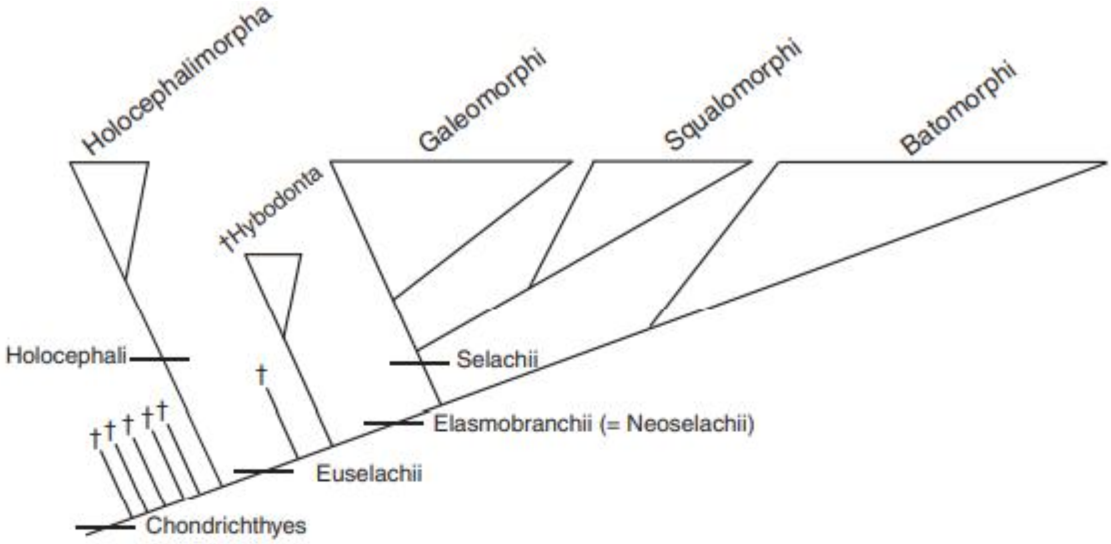
Include,

a. The Chondrichthyes (sharks and rays)
b. The Acanthodii, and
c. The Osteichthyes (bony fishes, including all tetrapods).

B.) **GRADE CHONDRICHTHIOMORPHI**

1. **Class CHONDRICHTHYES**- Cartilaginous fishes

- Dermal skeleton consisting of denticles (placoid scales)
- Skull lacks sutures in living forms
- Teeth are not fused to jaws and are replaced serially
- Fin rays soft, unsegmented
- Nasal openings on each side
- Endolymphatic duct present
- Swim bladder and lung absent
- Internal fertilization



Relationships of the major groups of Chondrichthyes.

Fig 1.18

OBTUSACANTHUS.

- Considered as a stem chondrichthyan

➢ **Order POLYMEROLEPIDIFORMES**.

- Laterally growing polyodontode scales of distinctive form
- Caudal fin heterocercal
- anal fin with small, leading-edge spine

➢ **Order OMALODONTIFORMES**.

- Large, paired pectoral fin spines
- Intact dentition

➢ **Order ANTARCTILAMNIFORMES**

- Paired (pectoral) fin spines
- Laterally growing polyodontode scales

➢ **Order PHOEBODONTIFORMES**

I. Superorder CLADOSELACHIMORPHA

- Cladodont-type tooth
- Claspers are absent

- Anal fin not present
- Paired fins in shape of triangular flaps.

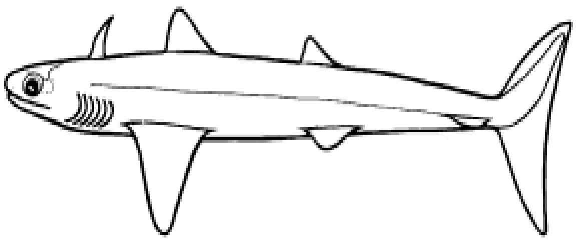


Fig 1.19 Cladoselache

➢ **Order CLADOSELACHIFORMES**.

- Two dorsal fins, at least a spine associated with the first

➢ **Order SYMMORIIFORMES**

II. Super Order CTENACANTHIMORPHA

➢ **Order CTENACANTHIFORMES.**

- Two dorsal fins, each with a spine
- Anal fin near caudal fin
- Cladodont-type tooth

➢ **Order SQUATINACTIFORMES**

III. **Superorder XENACANTHIMORPHA** (Pleuracanthodii)

➢ **Order BRANSONELLIFORMES**

➢ **Order XENACANTHIFORMES**.

- Pleuracanth-type tooth
- Claspers present in male
- Elongate dorsal fin base
- Diphycercal or heterocercal tail
- Two anal fins
- Cephalic spine

i. SUBCLASS HOLOCEPHALI

- Gill cover over the four gill openings
- Palatoquadrate fused to cranium
- 5 gill arches
- No spiracle opening;
- No stomach

- **Order INIOPTERYGIFORMES**
- **Order ORODONTIFORMES**
- **Order EUGENEODONTIFORMES**.
- **Order PETALODONTIFORMES** (Ray like body)
- **Order DEBEERIIFORMES**
- **Order HELODONTIFORMES**

IV. **Superorder HOLOCEPHALIMORPHA**

- Dentition consisting of a few large permanent grinding tooth plates
- Palatoquadrate fused to neurocranium (holostyly);
- Dorsal fin spine usually present.

- **Order PSAMMODONTIFORMES**.
- **Order COPODONTIFORMES**
- **Order SQUALORAJIFORMES**.(Body depressed)
- **Order CHONDRENCHELYIFORMES**.(Body elongate)
- **Order MENASPIFORMES**.
- **Order COCHLIODONTIFORMES**.
- **Order CHIMAERIFORMES -** chimaeras.(rat fishes or rabbit fishes)

ii. Subclass EUSELACHII (sharks, rays, and related fossils)

- Predaceous fishes
- Use smell and sight for obtaining foos
- Sharks, with lateral gill openings

- **Order PROTACRODONTIFORME**

Infraclass HYBODONTA(Hybodonts)

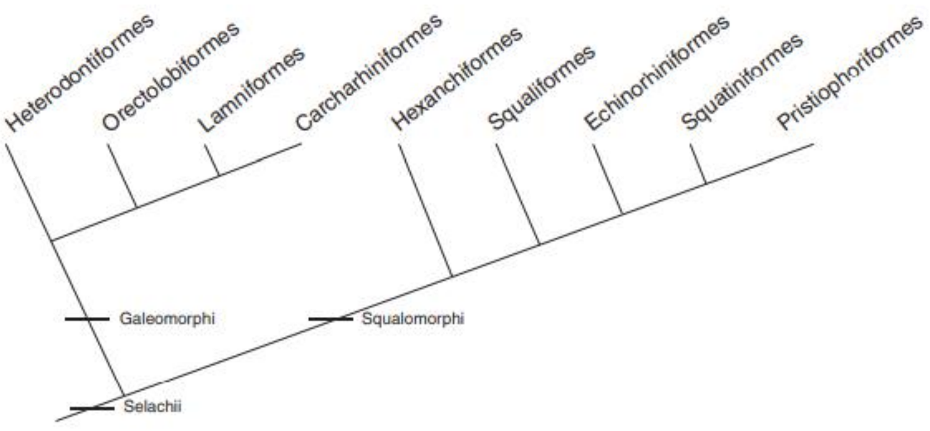
- **Order HYBODONTIFORMES**.
  - Males have hooked cephalic spines above the eye that may function as claspers during copulation.
  - 2 dorsal fins, with fin spine
  - Heterocercal tail

Infraclass ELASMOBRANCHII(=NEOSELACHII)

Includes all extant sharks and rays

Division SELACHII (sharks) (Selachimorpha, Pleurotremata)

- Gill openings mainly lateral
- Anterior edge of pectoral fin not attached to side of head
- Anal fin present or absent
- Pectoral girdle halves not joined dorsally



The Selachii (= Selachimorpha, Pleurotremata) contain two superorders, the Galeomorphi, with four orders, and the Squalomorphi with five orders, and a total of 34 families, 106 genera, and at least 513 species.

Fig 1.20

V. **Superorder GALEOMORPHI (anal fin present)**

- **Order SYNECHODONTIFORMES**

- **Order HETERODONTIFORMES** -bullhead sharks.
  - Two dorsal fins, each with a spine
  - Anal fin present
  - Head elevated with crests above eyes
  - Five gill slits,
  - Spiracle present but small
  - Eyes dorsolateral, without nictitating fold

Fig 1.21 Japanese bullhead shark

- **Order ORECTOLOBIFORMES -**carpet sharks.
  - Two dorsal fins, without spines
  - Anal fin present
  - Five gill slits
  - Eyes usually dorsolateral on head and without nictitating membrane;
  - Mouth small to large, well in front of the eyes;
  - Barbels present

- **Order LAMNIFORMES -** mackerel sharks.
  - Two dorsal fins, without spines
  - Anal fin present
  - Five gill slits
  - Spiracles usually present, small and behind eyes
  - Barbels absent

- Mouth large and extending well behind eyes

Fig 1.22 Mackerel shark

➢ **Order CARCHARHINIFORMES** -ground sharks.

- Two dorsal fins without spines
- Anal fin present
- Five gill slits,
- Eyes with nictitating fold or membrane
- Spiracles usually absent

VI. **Superorder SQUALOMORPHI**

SERIES HEXANCHIDA

➢ **Order HEXANCHIFORMES (Notidanoidei)** -six-gill sharks.

- One dorsal fin, without spine
- Anal fin present
- Six or seven gill slits
- Eyes without nictitating fold
- Spiracle present but small, well behind eye.

➢ **Order SQUALIFORMES -** dogfish sharks.

- Two dorsal fins, with or without spines
- Anal fin absent
- Five gill slits present
- Spiracles present

Fig 1.23 Dogfish Shark

SERIES SQUANTIDA

- **Order PROTOSPINACIFORMES**

- **Order ECHINORHINIFORMES -** bramble sharks.
  - Have thick selender body
  - Flattened head
  - Blunt snout
  - 5 pair of gill slits

- **Order SQUATINIFORMES -** angel sharks.
  - Flattened bodies
  - Broad pectoral fins
  - Smallest sized sharks
  - 2 spineless dorsal fins, no anal fins

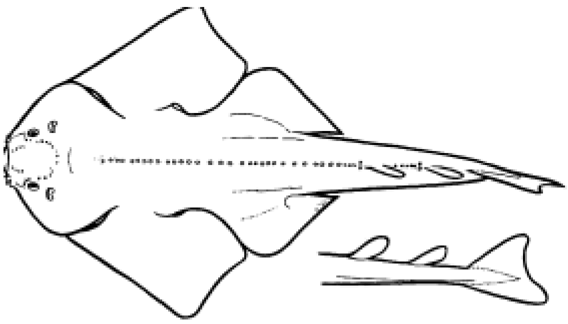


Fig 1.24 Angel shark

➢ **Order PRISTIOPHORIFORMES -** saw sharks.

- Body shark like
- Snout produced in a long flat blade with teeth on each side
- One pair of long barbels
- No dorsal fin spines

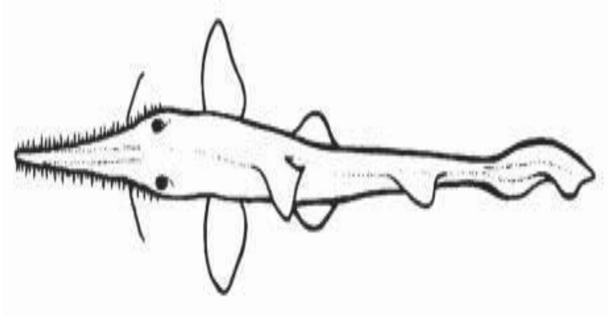


Fig 1.25 Saw shark

Division BATOMORPHI- rays

- Ventral gill opening
- Anal fin absent
- Eyes and spiracles on dorsal surface
- Nictitating membrane absent
- Jaws protrusible

➢ **Order TORPEDINIFORMES -** electric rays.

- Powerful electric organs, derived from branchial muscles in head region
- Skin soft and loose
- Eyes small to obsolete
- Caudal fin well developed
- Dorsal fins 0–2.

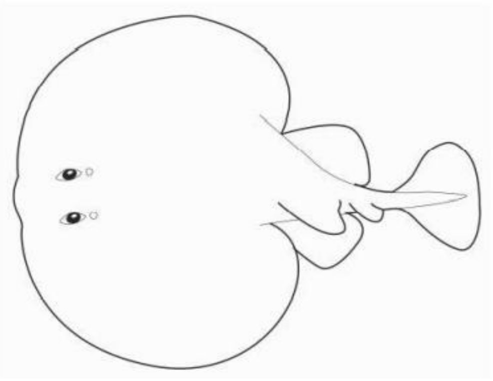


Fig 1.26 Torpedo electric ray

- **Order RAJIFORMES -** skates.
  - Caudal fin moderately well developed, reduced, or absent;
  - Tail extremely slender;
  - Dorsal fins 0–2
  - Claspers long, slender, and depressed distally.
  - Oviparous

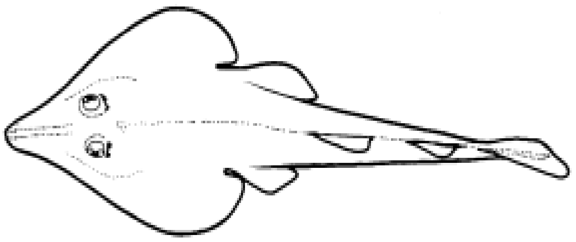


Fig 1.27 Skates

- **Order PRISTIFORMES –** guitarfish andsawfishes.
  - Snout produced in a long flat blade with teeth on each side
  - Barbels absent
  - The head is depressed;
  - Two distinct dorsal fins and a caudal fin.

- **Order MYLIOBATIFORMES -** stingrays.
  - Thornbacks have round or heart shaped pectoral disc
  - Long ,stout shark-like tail with 2 large dorsal fins
  - Strong thorns on dorsal surface of the disc and tail

A. **Grade TELEOSTOMI**

The following classes,

1. ACANTHODII
2. OSTEICHTHYES

1.) Class ACANTHODII - acanthodians

- Dermal and perichondral bone present
- Endochondral bone absent
- Ornamented plate like dermal cover over gill chamber in most species
- Jaws formed by palatoquadrate and Meckel's cartilage
- 5 gill arches
- Notochord persistent
- Rhombic to teardrop-shaped dermal scales present on body and fins
- Stout spines present before the dorsal, anal, and paired fins
- Caudal fin epicercal heterocercal.

Fig 1.28 Acanthodii

➢ **Order CLIMATIIFORMES**.

- Most with ornamented dermal bones in ventral portion of shoulder girdle
- Two dorsal fins, each with a spine;
- Teeth absent or, if present, not fused to jaws

➢ **Order DIPLACANTHIFORMES**.

- Had long median fin spines
- Single pair of pre pelvic spines between the pelvic and pectoral fins, or lacked such spines altogether.

- **Order ISCHNACANTHIFORMES**.
  - Two dorsal fins, each with a spine
  - Teeth fixed to strong dermal jaw bones
  - Pelvic spine absent

- **Order ACANTHODIFORMES**.
  - One posterior dorsal fin with spine
  - Teeth absent
  - Gill rakers well developed
  - Pre pelvis spines absent or 1 pair

2.) Class OSTEICHTHYES—bony fishes and tetrapods

- Skeleton with endochondral or membrane bone
- Skull have sutures
- Lung present

It includes all Sarcopterygii (the lobe-finned fishes including tetrapods) and all Actinopterygii (the ray-finned fishes).

Fig 1.28 Bony fish

I. **SubClass SARCOPTERYGII**—lobe-finned fishes and tetrapods

Infraclass ACTINISTIA – coelacanths (Coelacanthida)

- **Order COELACANTHIFORMES** - coelacanths.
  - Caudal fin diphycercal, consisting of 3 lobes
  - External nostrils
  - Branchiostegals absent

- Anterior dorsal fin in front of center of body.

Infraclass ONYCHODONTIDA

- **Order ONYCHODONTIFORMES** (Struniiformes).

Infraclass DIPNOMORPHA

i. **Superorder POROLEPIMORPHA**

- **Order POROLEPIFORMES** (Holoptychiiformes).
  - Body plump
  - Pectorals inserted relatively high on body
  - Thick rhomboid cosmoid scales present

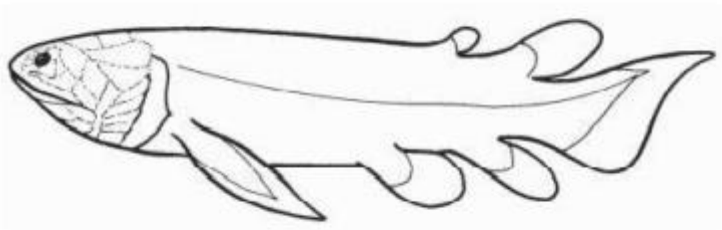


Fig 1.29 Porolepis

ii. Superorder DIPNOI

- Labial cavity present
- B-bone present
- Include all lungfishes

Fig 1.30 Dipnoi

- **Order DIABOLEPIDIFORMES**
- **Order DIPNORHYNCHIFORMES.**
- **Order DIPTERIFORMES**
- **Order CTENODONTIFORMES**
- **Order CERATODONTIFORMES-** living lungfishes and their fossil relatives

Infraclass RHIZODONTIDA (Rhizodontimorpha)

- **Order RHIZODONTIFORMES**

Infraclass OSTEOLEPIDIDA

- **Order OSTEOLEPIDIFORMES**.
  - Body slender
  - Pectorals usually inserted low on body
  - Thick rhombic scales
  - Pineal foramen present

Infraclass ELPISTOSTEGALIA

- **Order ELPISTOSTEGALIFORMES**
  - Median supraorbital ridges present
  - Paired fins

Infraclass TETRAPODA- Tetrapods

Subclass ACTINOPTERYGII—the ray-finned fishes

- Scales ganoid, cycloid, or ctenoid
- Spiracle usually absent
- Inter opercle and branchiostegal rays usually present
- Internal nostrils absent
- Nostrils relatively high up on head.

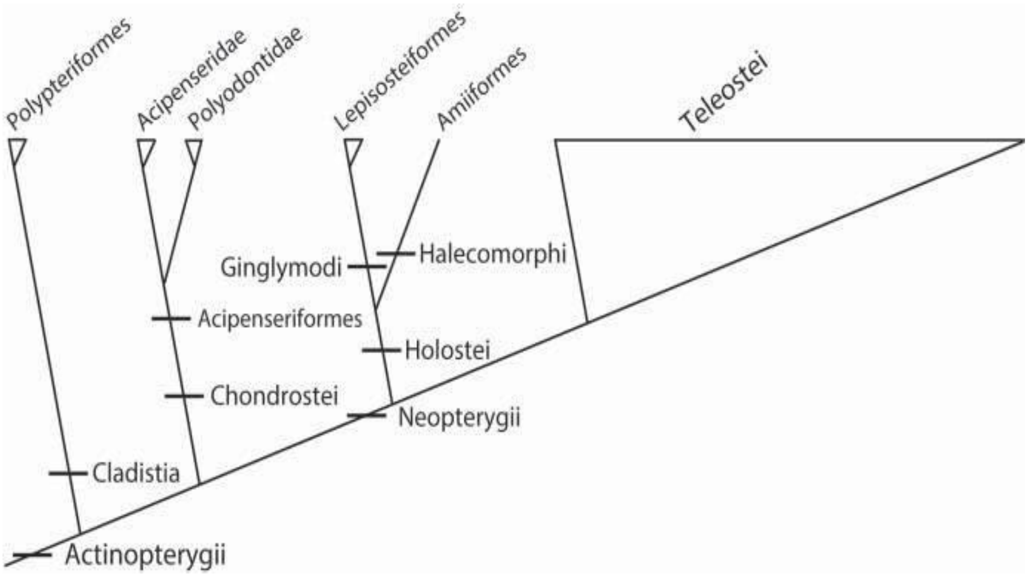


Fig 1.31 Phylogeny of the main extant groups of Actinopterygii

Taxa included as primitive stem actinopterygians :

➢ **Order CHEIROLEPIDIFORMES**.

- Its species C. canadensis, may hold the record for having the largest number of pelvic fin rays, up to 124

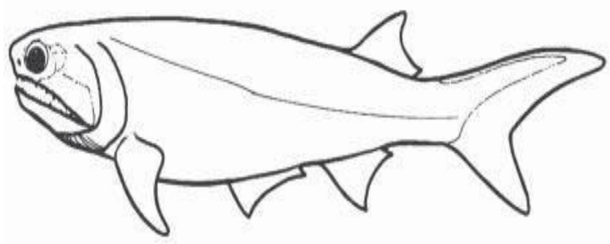


Fig 1.32 C. Canadensis

- **Order PALAEONISCIFORMES**.
  - The cheekbones form a solid unit (the maxilla, preopercles, and suborbitals are firmly united)
  - The eyes are large and far forward
  - The tail is strongly heterocercal.
  - More advanced forms had a hyomandibular in the vertical plane and a breakup of the cheekbones.

- **Order DORYPTERIFORMES**.
  - Body deep and mostly scale-less
  - Pelvic fin in front of pectorals
  - Caudal peduncle very narrow.

- **Order PLATYSOMIFORMES.**
  - Body deep and compressed

- **Order TARRASIIFORMES**
  - Diphycercal caudal fin
  - Pelvic fin absent
  - Continuous dorsal and anal fin
  - Scales reduced or absent

- **Order GUILDAYICHTHYIFORMES**.
- **Order PHANERORHYNCHIFORMES**
- **Order SAURICHTHYIFORMES**

- **Order REDFIELDIIFORMES.**
  - Fusiform body
  - Terminal or sub terminal mouth
  - Branchiostegal rays reduced to 1 or 2 plate –like bones

- **Order PTYCHOLEPIFORMES**.
- **Order PHOLIDOPLEURIFORMES.**
- **Order PERLEIDIFORMES.**
- **Order LUGANOIIFORMES**.

All of the remaining taxa are members of the crown-group actinopterygii

Infraclass CLADISTIA

- **Order POLYPTERIFORMES (Brachiopterygii)** - bichirs.
  - Rhombic ganoid scales
  - 5-18 finlets in dorsal fin
  - Numerous ossified radicals in pectoral fin
  - Maxilla united to skull
  - Lungs partially used in respiration

Infraclass CHONDROSTEI

- **Order CHONDROSTEIFORMES**

- **Order ACIPENSERIFORMES – paddlefishes and sturgeons.**
  - Caudal fin heterocercal;
  - Myodome and preopercle reduced or absent
  - Skeleton largely cartilaginous
  - Fin rays more numerous than their basals

NEOPTERYGII (unranked)

- Fin rays equal in number to their supports in dorsal and anal fins;
- Premaxilla with internal process lining the anterior part of nasal pit

- **Order PYCNODONTIFORMES**.
  - Group of reef- or lagoon-dwelling fishes
  - Crushing dentition

Infraclass HOLOSTEI (gars, bowfins, and relatives)

Division GINGLYMODI (include gars)

- **Order DAPEDIIFORMES**

- **Order LEPISOSTEIFORMES -gars**.
  - Body and jaws elongate

- Mouth with needle like teeth
- Abbreviated needle like tail

- **Order SEMIONOTIFORMES**

- **Order MACROSEMIIFORMES.**

Division HALECOMORPHI

- **Order PARASEMIONOTIFORMES**.

- **Order IONOSCOPIFORMES**

- **Order AMIIFORMES - bowfins.**
    - 2 or lesss ossified ural neural arches
    - Opisthotic bone lost

Division TELEOSTEOMORPHA

Subdivision ASPIDORHYNCHEI

- **Order ASPIDORHYNCHIFORMES**

- **Order PACHYCORMIFORMES**
    - Median rostrodermethmoid separating the premaxillary bones
    - Hypural plate

Subdivision TELEOSTEI

- **Order PHOLIDOPHORIFORMES**.
- **Order DORSETICHTHYIFORMES**
- **Order LEPTOLEPIDIFORMES.**
- **Order CROSSOGNATHIFORMES**

- **Order ICHTHYODECTIFORMES.**

- Anal fin long usually with 24–37 rays
- Posteriorly situated dorsal fin of 10–18 rays

➢ **Order TSELFATIIFORMES**.

- Body deep
- Mouth bordered by premaxilla and maxilla
- Dorsal fin extending along most of back
- Pelvics absent or present with six or seven rays
- Caudal fin deeply forked with 18 principal rays
- Most fin rays unsegmented

➢ **Order ARARIPICHTHYIFORMES**

- Deep body
- Dorsal and anal fin with long base
- Caudal fin forked

Supercohort TELEOCEPHALA—crown-group Teleostei

Cohort ELOPOMORPHA

Elopomorpha include four orders:

i. Elopiformes (ten-pounders)
ii. Albuliformes (bonefishes)
iii. Notacanthiformes (halosaurs and deep-sea spiny eels) and
iv. Anguilliformes (eels).

➢ **Order ELOPIFORMES -** tenpounders.

- Pelvic fins abdominal
- Body slender, usually compressed
- Gill openings wide
- Caudal fin deeply forked
- Scales cycloid
- Gular plate well developed
- Branchiostegal rays 23–35
- Small Leptocephali

- **Order ALBULIFORMES** - bonefishes.
  - Mandibular sensory canal lying in an open groove in the dentary and angular bones

- **Order NOTACANTHIFORMES** - halosaurs and deep-sea spiny eels.
  - Eel-like body
  - Separate gill membrane
  - Pectoral fins relatively high on body
  - Abdominal pelvic fins
  - Tail easily regenerate when lost
  - Leptocephalus larva

- **Order ANGUILLIFORMES** (Apodes) - eels.
  - Pelvic fins and skeleton absent
  - Pectoral fins and girdle absent in some
  - Scales usually absent or, if present, cycloid and embedded;
  - Body very elongate (eel-like)
  - Gill rakers absent
  - Pyloric caeca absent
  - Branchiostegal rays 6–49
  - Swim bladder present
  - All or most of the gonads are in the tail (post anal) in some groups

OSTEOGLOSSOCEPHALA

COHORT OSTEOGLOSSOMORPHA

- **Order LYCOPTERIFORMES**
- **Order HIODONTIFORMES** - mooneyes.
- **Order OSTEOGLOSSIFORMES** -bonytongues.
  - Caudal fin with 16 or fewer branched rays;
  - Nasal capsule rigid,
  - Epipleural intermuscular bones absent
  - One or two pyloric caeca

CLUPEOCEPHALA

Cohort OTOCEPHALA (= OSTARIOCLUPEOMORPHA, OTOMORPHA)

i. **Superorder CLUPEOMORPHA**

- **Order ELLIMMICHTHYIFORMES**.
  - Lateral line complete
  - Large foramen in anterior ceratophyal

- **Order CLUPEIFORMES** - herrings.
  - Parasphenoid teeth absent;
  - No leptocephalus larvae.
  - Most are plankton feeders, with long and sometimes very numerous gill rakers that serve as straining devices.

Fig 1.33 Herring

ii. **Superorder ALEPOCEPHALI**

- **Order ALEPOCEPHALIFORMES - slickheads and tubeshoulders**
  - Adipose fin absent
  - Swimbladder absent
  - Large mouth

Fig 1.34 Alepocephalidae

iii. **Superorder OSTARIOPHYSI**

- Swim bladder present (except in Gonorynchus)
- Minute, unicellular, horny projections, termed "unculi," commonly present on various body parts
- Upper jaw protractile in many species.
- Pelvic fins, if present, abdominal.

Series ANOTOPHYSI

- **Order GONORYNCHIFORMES** - milkfishes.
  - Teeth absent on fifth cerato-branchial
  - Suprabranchial (= epibranchial) organ present
  - Mouth small
  - Jaws toothless;
  - 5–7 hypural plates.

Fig 1.35 Milk fish

Series OTOPHYSI

- Weberian apparatus present
- Distinctive modification of anterior four or five vertebrae;
- Movable bony ossicles connect the swim bladder to the inner ear for sound transmission known as the Weberian ossicles,

- **Order CYPRINIFORMES** – carps,loaches, minnows

- Kinethmoid present (a median bone between ascending processes of premaxillae)
- Upper jaw usually protractile
- Mouth (jaws and palate) always toothless;
- Adipose fin absent (except in some cobitoids);
- 3 branchiostegal rays
- Spine like rays in dorsal fin of some species

Fig 1.36 Minnow

➢ **Order CHARACIFORMES** - characins.

- Teeth usually well developed (most are carnivores)
- Adipose fin usually present
- Body almost always scaled ,ctenoid or ctenoidlike scales in some
- Pelvic fin present (with 5–12 rays)
- Anal fin short to moderately long (fewer than 45 rays)
- Pharyngeal teeth usually present
- Barbels absent
- Branchiostegal rays 3–5;
- Some characiforms lack the adipose fin

SUBSERIES SILURIPHYSI

➢ **Order SILURIFORMES** (Nematognathi) - catfishes.

- Dorsal and anal-fin pterygiophores lacking middle radial ossification
- Adipose fin usually present
- Spinelike (= spinous) rays often present at the front of the dorsal and pectoral fins
- Body naked or covered with bony plates;

- Normally up to four pairs of barbels on head, one nasal, one maxillary, and two on chin (i.e., on the lower jaw or mandible),
- Eyes usually small (barbels are important in detecting food);
- Air breathing

➢ **Order GYMNOTIFORMES** - American knifefishes.

- Body eel-like (compressed or cylindrical)
- Pelvic girdle and fins absent
- Dorsal fin absent
- Anal fin extremely long
- Caudal fin absent or greatly reduced
- Anal opening under head or pectorals
- Electric organs present
- The electric organs are derived from muscle cells in most groups (myogenic), or from nerve cells in adult apteronotids (neurogenic)

Fig 1.37 Electrophorus electricus

Cohort EUTELEOSTEI

(This taxon contains all the remaining teleost fishes)

➢ **Order LEPIDOGALAXIIFORMES - salamanderfishes**

- Elongate and slender shaped body
- Dorsal fin posterior to pelvic fin
- No adipose fin

- Thin scale

Superorder PROTACANTHOPTERYGII

- **Order SALMONIFORMES – trouts, salmons and whitefish**
    - Basihyal teeth present
    - Vertebral centra pitted
    - 7-20 branchiostegal rays
    - Tetraploid karyotype

Fig 1.38 Rainbow trout

- **Order ESOCIFORMES (Haplomi, Esocae) pikes and mudminnows**
    - Maxilla toothless
    - No adipose fin;
    - Dorsal and anal fins located posteriorly;
    - No breeding tubercules

Superorder OSMEROMORPHA

- **Order ARGENTINIFORMES-** marine smelts.
    - Adipose fin present
    - Crumenal organ present
    - Toothless maxillae and premaxillae
    - Small mouth
    - 2-7 branchiostegal rays

- **Order GALAXIIFORMES - galaxiiforms.**
    - No pyloric caeca
    - Mesocoracoid and supermaxillae absent

- 18 or less caudal fin rays

➢ **Order OSMERIFORMES** -freshwater smelts.

- Mesopterygoid teeth reduced
- Adipose fin present or absent
- Radii absent on scales

➢ **Order STOMIIFORMES** (Stomiatiformes) - dragonfishes.

- Luminescent organs (photophores) present
- Chin barbel present in some
- Scales cycloid
- Pectoral, dorsal, or adipose fins absent in some
- Pelvic fin rays 4–9
- Branchiostegal rays 5–24.

Superorder ATELEOPODOMORPHA

➢ **Order ATELEOPODIFORMES** - jellynose fishes.

Superorder CYCLOSQUAMATA

➢ **Order AULOPIFORMES** - lizardfishes.

- Swim bladder absent
- Medial processes of pelvic girdle fused

1.39 Indian lizardfish

Superorder SCOPELOMORPHA

➢ **Order MYCTOPHIFORMES -** lanternfishes

- Head and body compressed
- Eye lateral
- Mouth usually large and terminal
- Adipose fin present
- 8 pelvic fin rays
- 7–11 branchiostegal rays.

➢ **Order CTENOTHRISSIFORMES**

Superorder LAMPRIMORPHA

➢ **Order LAMPRIFORMES (**Lampridiformes, Allotriognathi)- opahs.

- No true spines in fins
- unique type of protrusible upper jaw
- Pelvic fins with 0–17 rays

Superorder PARACANTHOPTERYGII

➢ **Order POLYMIXIIFORMES - beardfishes.**

- Have palato-premaxillary ligament passing between maxillary lateral processes, rather than between contralateral palatines

➢ **Order SPHENOCEPHALIFORMES.**

- "Gadoid notch" present
- Sphenocephalus has a small supramaxilla
- Lacks an adipose fin.

➢ **Order PERCOPSIFORMES** - trout-perches.

- Premaxilla nonprotractile
- Pelvic fins, if present, behind pectorals and with 3–8 soft rays
- Spines usually present in dorsal fin
- Ctenoid scales
- Six branchiostegal rays
- Vertebrae 28–35.

➢ **Order ZEIFORMES -** dories.

- Dorsal, anal, and pectoral fin rays unbranched
- Palatine teeth absent; vomerine teeth present
- Caudal fin usually with 11 branched rays
- Dorsal fin with 5–10 spines and 22–36 soft rays;
- Body usually thin and deep
- Vertebrae usually 30–44.

➢ **Order STYLEPHORIFORMES - tube-eyes or thread-tails.**

- Ribbon like body
- Fin extending from nape to tail
- Caudal fin in two parts

Fig 1.40 Stylephorus

➢ **Order GADIFORMES** - cods.

- Pelvic fins, when present, inserted below or in front of pectorals with up to 11 rays
- No true spines in the fins
- Most with long dorsal and anal fins
- Scales usually cycloid, rarely ctenoid
- 6-8 branchiostegal rays
- Swim bladder without pneumatic duct

Superorder ACANTHOPTERYGII

Series BERYCIDA

➢ **Order HOLOCENTRIFORMES -squirrelfishes**

- Pelvic fin with 2 spine
- Long dorsal fin with spiny portion
- Anal fin with 4 spines

- Caudal fin forked

- **Order TRACHICHTHYIFORMES -roughies.**
  - Distinctive X pattern of frontal ridges
  - Small ethmoid
  - Eyes small

- **Order BERYCIFORMES - beryciforms.**
  - Roundish body
  - Toothless palate
  - Subocular shelf absent

Series PERCOMORPHA

- Pelvic girdle is directly or ligamentously attached to the cleithrum or coracoid of the pectoral girdle

Subseries OPHIDIIDA

- **Order OPHIDIIFORMES - cusk-eels.**
  - Pelvic fins have 1 or 2 soft rays in each
  - Long base of dorsal and anal fin
  - Paired nostril on each side

Subseries BATRACHOIDIDA

- **Order BATRACHOIDIFORMES** (Haplodoci) - toadfishes.
  - Body usually scaleless (small cycloid scales in some);
  - 3 pairs of gills
  - 6 branchiostegal rays
  - Four or five pectoral radials;
  - Swim bladder present
  - No pyloric caeca.
  - Some members can produce audible sounds with the swim bladder

Subseries GOBIIDA.

- **Order KURTIFORMES – nursery fishes and cardinalfishes**
    - Horizontal and vertical rows of sensory papillae on the head and body(a grid pattern)
    - Single dorsal fin
    - Caudal fin deeply forked

- **Order GOBIIFORMES - gobies.**
    - Parietals absent
    - Infraorbitals unossified or absent
    - Some have barbels on head
    - Pelvic fin below pectoral

Subseries OVALENTARIA

- Loss of interarcual cartilage
- Loss of supraneurals

- **Order MUGILIFORMES** - mullets.(ray- finned fish)
    - Selender bodies
    - 2 widely separated dorsal fins
    - Forked tail
    - Small triangular mouth
    - Lateral line organ absent

Fig 1.42 Mullet

- **Order CICHLIFORMES - cichlids and convict blennies**
    - Single nostril on each side

- 20-50 scale in lateral line
- 4-15 soft rays in anal fin
- No subocular shelf

- **Order BLENNIIFORMES -Blennies.**
  - Pelvic fin with 1 embedded spine
  - Anal fin with less than 3 spine
  - 6 branchiostegal rays
  - 2 nostril on each side

- **Order GOBIESOCIFORMES -clingfishes.**

- **Order ATHERINIFORMES** - silversides.
  - Usually two separated dorsal fins, the first, if present, with flexible spines, and the second preceded by a single flexible spine in most species
  - Anal fin usually preceded by a spine;
  - Lateral line absent or very weak;
  - Branchiostegal rays 4–7;
  - Nasal openings paired

- **Order BELONIFORMES** - needlefishes.
  - Interarcual cartilage small or absent
  - Interhyal absent;
  - A fixed or nonprotrusible upper jaw.

- **Order CYPRINODONTIFORMES** (Microcyprini) - killifishes.
  - Caudal fin truncate or rounded;
  - Lateral line canal and pores chiefly on head
  - Lateral line represented on body only by pitted scales;
  - Branchiostegal rays 3–7;
  - Pelvic fins and girdle present or absent
  - Vertebrae 24–54.

- **Order SYNBRANCHIFORMES - swamp eels.**

- Body elongate
- Pelvic fins absent
- Gill openings confined to lower half of body
- Premaxillae non protrusible and without ascending process.

➢ **Order CARANGIFORMES - jacks.**

- 1 or 2 tubular ossifications around extension of nasal canal
- Small adherent cycloid scales present

➢ **Order ISTIOPHORIFORMES - barracudas and billfishes.**

- Fast swimmers
- Cranial endothermy (maintain high brain and retinal temperature)
- Barracudes have elongate body and large mouth

➢ **Order ANABANTIFORMES (Labyrinthici) - labyrinth fishes**

- Suprabranchial organ present
- Larvae have bilateral pair of oil vesicles used as floating device

➢ **Order PLEURONECTIFORMES (Heterosomata) - flatfishes**

- Adults are not bilaterally symmetrical
- Dorsal and anal fins are with long bases
- Highly compressed body
- 6 or 7 branchiostegal rays
- Small body cavity
- Adults almost always without swim bladder;
- Scales cycloid, ctenoid, or tuberculate.

➢ **Order SYNGNATHIFORMES - pipefishes and seahorses.**

- Small mouth, tube like snout
- Abdominal pelviv fin(if present)
- No protactile upper jaw
- Lachrymal present
- Ribs absent
- Aglomerular kidney in some

- **Order ICOSTEIFORMES (Malacichthyes) - ragfishes.**
  - Elliptical body
  - Cartilaginous skeleton
  - Fins donot have spines
  - Minute prickles on fin rays

- **Order CALLIONYMIFORMES**
  - Depresses and broad head
  - Scaleless body
  - Small mouth
  - One spine in pelvic fin

- **Order SCOMBROLABRACIFORMES - longfin escolars.**
  - Protractile premaxillae
  - Serrated preopercle and opercle
  - Swimbladder with thin, elastic walls

- **Order SCOMBRIFORMES (Pelagia) -mackerels.**
  - Upper jaw not protrusible
  - Oblong or elongate and compresses body
  - Lower jaw is protruding
  - Very long teeth
  - 1-3 spines on anal fin
  - Caudal fin present

- **Order TRACHINIFORMES**
  - Swallowers have highly distensible mouth and stomach
  - Sandperches have protractile and terminal mouth

- **Order LABRIFORMES - wrasses and relatives.**
  - 5^{th} ceratobranchials are fused to form single lower pharyngeal jaw
  - Most species are protogynous
  - Mouth protractile or nonprotractile

- **Order PERCIFORMES - perches.**
    - The largest order of vertebrates.
    - Dorsal and anal fin divided into anterior spiny and posterior soft- rayed portions.
    - Pelvic fins have 1 spine and 5 soft rays
    - Anal fin has spine
    - Ctenoid scales

Fig 1.42 Perch

- **Order SCORPAENIFORMES - mail-cheeked fishes.**
    - Presence of suborbital stay, a posterior extension of the third infraorbital bone
    - Head and body tend to be spiny or have bony plates
    - Pectoral fin usually rounded

- **Order MORONIFORMES - temperate basses.**
    - 2 dorsal fins , 1st with 8-10 spines and 1 spine in 2nd
    - 3 spines in anal fin
    - Lateral line extends to posterior margin of caudal fin
    - 7 branchiostegals

- **Order ACANTHURIFORMES- surgeon fishes and relatives.**
    - Jaws toothless
    - Rovers have large Rostral cartilage
    - Surgeon fish have pelvic fin with 1 spine

- **Order SPARIFORMES - breams and porgies.**

- Splendid perches have flat nasal organ devoid of lamellae
- Tripletails have rounded caudal fin
- Threadfin breams filamentous off upper lobe in caudal fin

➢ **Order CAPROIFORMES – boarfishes**

- Percoid type of caudal skeleton
- In boarfishes body covered with small ctenoid scales
- Rounded caudal fin

➢ **Order LOPHIIFORMES anglerfishes.**

- First ray of spinous dorsal, if present, on head and transformed into illicium (line) and esca (bait)
- Small, tube like Gill opening at or behind pectoral fin base;
- 5 -6 branchiostegal rays;
- First vertebra fused to skull;

➢ **Order TETRAODONTIFORMES (Plectognathi) - plectognaths.**

- No nasals and ribs
- Scales usually modified as spines, shields, or plates
- Lateral line present or absent, sometimes multiple
- Swim bladder present
- Tetraodontiformes can produce sounds by grinding the jaw teeth or the pharyngeal teeth or by vibrating the swim bladder.

1.4 HABIT AND HABITAT

In fisheries Food and feeding pattern or habit is very important factor that helps to choose the fish type for cultivation.

It helps to avoid fight among them for getting food in different water levels.

According to their feeding habits fishes are

- Carnivorous
- Herbivorous
- Omnivorous

While a large portion of them are adaptable in their feeding habits and use the promptly available diet. Only a few fish groups are strictly herbivorous or carnivorous and the available food helps to decide if it will be eaten by the fish.

Fishes show diversity in behavior and variety of foods adapted to feed on zooplankton, snails, and coral, many classes of animal and some plants.Fishes can eat plants, macro algae (seaweed), plankton (microscopic animals and plants), invertebrates (mosquito larvae, dragonflies, and shrimp) and even other fish. These also needs particular habitat conditions for better survival.

A habitat is an ecological or environmental area inhabited by one or more living species.

Fish habitat means a place used by any fish at any stage at any time of the year.

Fishes have difference in shape, size, eating quality, fighting ability, reproduction and growth but they all have a common characteristic, i.e. they all depend on habitat and the type of habitat may sometimes depend on their stage of life. The water in which fish live has to be the right type whether it is freshwater, estuarine or saltwater.

Fish habitat is more than just the water it includes:

- The materials that provide the underlying structure: e.g. rocks, coral, gravel, sand and mud
- Types of vegetation present: e.g. overhanging vegetation, reeds, water plants, algae, dead wood (snags), seaweeds, sea grasses, mangroves and saltmarsh
- Shape and nature of the habitat: e.g. pools and riffles, billabongs and reefs
- Connections to other water bodies and ecosystems. Like streams, beaches, estuaries

According to the NSW Fisheries Management Act 1994 fish habitat means: any area occupied, or periodically or occasionally occupied, by fish or marine vegetation (or both), and includes any biotic (living) or abiotic (non-living) component

In freshwater, fishes take shelter under in-stream structure, such as rocks, submerged logs and branches (snags), vegetation and deep pools or undercut banks. In estuaries, sea grasses and mangrove forests provide shelter for juvenile fish from predators. Any change to habitat may not affect the fish directly but their food source. Any change in fish habitat can affect its survival like some changes lead to destruction of hiding place of juvenile and adult fish making them vulnerable to predators.

Fishes live in most type of aquatic habitat like in Lake Baikal, the world’s deepest lake (at least 1,000 m), and 7,000 m below the surface of the ocean. Even some fish species have acquired air-breathing organs and can live in stagnant, tropical swamps.

Based on temperature tolerance fishes can be of two types

i. **Eurythermal:** wide temperature tolerance**.**
ii. **Stenothermal:** narrow range of temperature tolerance**.**

Based on salinity tolerance fishes are

i. **Euryhaline :** Fishes that can tolerate a wide range of salinity
ii. **Stenohaline :** that can tolerate a narrow range of salinity.

Some fishes can survive in pure freshwater (0.01 ppt total dissolved solids) and in very salty lakes (100 ppt).

Thus based on salinity fishes are divided into

a) **Brackishwater Fish**: fishes that tolerate a wide range of salinity (0.5 – 30.0 ppt).
Mostly found in backwaters, estuaries and coastal waters.
Example: Mullet, Milkfish, Seabass,Pearlspot, Mudskipper, etc.

b) **Marine Fish**: Fish that live most of their life in seawater, like Seas and Oceans,having salinity above 30 ppt.
Example: Sardines, Mackerel, Ribbonfish, Anchovies, Grouper, Cobia, Tuna, etc.

Fishes (Subterranean, or hypogean) can survive in total darkness in caves or other underground areas, or—as in Tibet, China, and India to fast torrential streams.

Oreochromis alcalicus or *Alcolapia graham* (soda tilapia), occurs in hot soda lakes in Lake Magadi, Kenya, that have temperatures as high as 42.5ºC.

Freshwater ecosystems are a subset of Earth's aquatic ecosystems. They include lakes, ponds, rivers, streams, springs, bogs, and wetlands

Ponds and lakes

Ponds and lakes are called lentic ecosystems, i.e. that they have still or standing waters

The temperature of lakes can change depending on where they are and what time of year it is

In Freshwater the preferred environments are

- **Lake**: Fish are mostly found in the open water limnetic zone, the benthic area or shallow littoral areas.

  Species are found in deep, cold, oligotrophic lakes or shallower, warmer, and more productive mesotrophic and eutrophic lakes. Some fishes are found only at bottom.

- **Stream:** fishes are found in riffle or quiet areas, from the headwaters to the mouth.

Marine habitat can be divided into coastal and open Ocean.

- ✓ **Coastal habitat:** Area that extends from as far as the tide comes in on the shoreline out to the edge of the continental shelf. It is found in tidal pools, near sandy shores and rocky coastlines, around the coral reefs and on or above the continental shelf.Most marine life is found in coastal habitats
  - Coastal fish includes small forage fish as well as larger predatory fishes. Some fishes live here for some part of their life and spawns in streams, estuaries and bays.
  - In tropical and temperate areas Mangrove swamps and salt marshes are important coastal habitats.
  - An estuary is partly enclosed coastal water body, one or more rivers or streams flow into it and has connection to the open sea. As in estuaries there is inflow of both freshwater ans seawater providing high level of nutrients making them the most productive natural habitats in the world.

- ✓ **Open ocean habitats**: Found in the deep ocean beyond the edge of the continental shelf.

1.5 DISTRIBUTION PATTERN

Fishes can survive in nearly all major aquatic habitats that have liquid water , from lakes and polar oceans that are ice-covered, to tropical swamps, temporary ponds, intertidal pools, ocean depths, thermal and alkaline springs, hypersaline lakes, sunless caves, , torrential rivers, wave-swept coasts, and high-altitude and high-latitude environments.

To survive in such a variety of environments, fishes have evolved striking anatomical, physiological, behavioral, and ecological adaptations, illustrated by extensive fossil record dating back more than 500 million years.

As 71% of the planet’s surface is covered with water, water supports life from the surface down to the oceans’ greatest depths of 11,000 m. Fishes live in fresh water or marine water and occur in lakes, streams, estuaries, and oceans throughout the world.

Fish distribution is mainly divided into two major components:

1. Marine (58 %)

2. Freshwater (41%): Fish that spend most or all of their life in freshwaters, such as rivers, lakes, ponds having a salinity of less than 0.5 ppt.

Four main ecological divisions are recognized among the species of marine fishes:

i. Epipelagic fishes: dwell from the surface down to 200 m .1.3% of the total, or about 360 species.
ii. Deep pelagic fishes: 1400 species, or about 5% of the total.
 Water column dwelling fishes are subdivided into
 a) Mesopelagic fishes: which live between 200 and 1000 m, and
 b) Deeper dwelling bathypelagic fishes.
iii. Deep benthic fishes: 1800 species, or 6.4% of the total.
iv. Littoral or continental shelf species: shallow dwelling fishes. Inhabit the shore and shelf above 200 m

Distribution of inshore marine fishes is into four major marine regions (order of decreasing biodiversity)

(i) Indo-West Pacific
(ii) Western Atlantic
(iii) Eastern Pacific
(iv) Eastern Atlantic**.**

- Continents or large expanses of open ocean separate these regions from each other and been subdivided into different units by different authors.
- Most Ocean water of world lie below euphotic zone where primary productivity occurs. Coastal zones support 45% of total fish species as these are shallow productive to support diverse fauna.
- Marine habitat are mostly continuous, faunal breaks occur where continental landmasses, large rivers, or sills occur, and oceanic currents act as geographic boundaries.
- Also marine fishes face land barriers and mid-ocean barriers, ecological and physiological barriers.
- The maximum diversity of marine fish species is in tropical waters.

Freshwater fishes are classified according to water temperature in which they survive.as the water temperature affects amount of oxygen present.

i. **Coldwater**: fish species that survive in the coldest temperature (10-16^{o}C).Common coldwater fish include brook trout, rainbow trout, and brown trout.

ii. **Cool water**: fishes that prefer temperature between (16–27 °C). Common cool water species include muskellunge, northern pike, walleye, and yellow perch.

iii. **Warm water:** fish species can survive in a wide range of conditions, preferring a water temperature around 27 °C.

Warm water fish can survive cold winter temperatures in northern climates, but thrive in warmer water. Example: catfish, largemouth bass, bluegill, crappies, and many other species from the family Centrarchidae.

In most fishes all individuals live in fresh water or marine water. But some species are diadromous i.e. live part of their lives in rivers and lakes and part in oceans. These are

1. **Anadromous**: spawning in freshwater but spending much of their time in the sea.

2. **Catadromous**: spawning in the oceans but returning to freshwater.

Freshwater fishes make a much larger contribution to biodiversity.

- Most of the freshwaters are shallow and receive significant sunlight that allow photosynthesis and forms base of food webs.
- Fresh waters are frequently and readily broken up into isolated water bodies. Some of the agents that lead to water body lose its connection with other bodies and thus isolate the fishes causing genetic isolation are drought, volcanoes, landslides, tectonic uplifting, glacial retreat, and dam building by beavers.
- The driving force of evolution is Genetic isolation that lead to events as explosive speciation and formation of species flocks.
- Some freshwater and marine species are also common in brackish-water estuaries.
- Environmental factors influence the predominance of certain species. Competition and other biological interactions, physicochemical factors influence the movement of fishes.
- Fish species are found in both the Pacific and Atlantic and maximum number of fish species in the world inhabit the southeastern Asian region.
- The majority of species are tropical while others occur only in the Northern or only in the Southern Hemisphere.
- Freshwater fish species occur in tropical Africa, southeastern Asia, and the Amazon River (the world’s largest river). Few freshwater species are found in Central America (tropical region).

- While the Indo- West Pacific show richest marine diversity.
- The West Indian or Caribbean fauna is also rich.

1.6 SUMMARY:

- Carolus Von Linnae is father of taxonomy.
- Taxonomy is a part of systematics that deals with the theory and practice of describing diversity and erecting classifications.
- Classification is the arranging of fishes into group or categories.
- Fishes arose more than 500 million years ago and exhibit diversity in their morphology, habitat , physiology and behavior.
- As 71% of the planet’s surface is covered with water, water supports life from the surface down to the oceans’ greatest depths of 11,000 m.
- Fish diversity helps to understand their evolutionary history and establish classification.
- Fishes evolved during Ordovician period. Ostracoderms are the first fossil records found in the rocks of Ordovician period.During Devonian period the first jawed fishes, the Placoderms evolved. Also called the “the golden age of fishes.
- During Devonian period the first jawed fishes, the Placoderms evolved. Also called the “the golden age of fishes.
- Different classifications are given by Cuvier, Agassiz, Linnaeus, Muller, Jordan, Berg , Romer , During Devonian period the first jawed fishes, the Placoderms evolved. Also called the “the golden age of fishes Parkers and Haswell and Nelson.
- Fishes can survive in nearly all major aquatic habitats that have liquid water , from lakes and polar oceans that are ice-covered, to tropical swamps, temporary ponds, intertidal pools, ocean depths, thermal and alkaline springs, hypersaline lakes, sunless caves, , torrential rivers, wave-swept coasts, and high-altitude and high-latitude environments.
- To survive in such a variety of environments, fishes have evolved striking anatomical, physiological, behavioral, and ecological adaptations, illustrated by extensive fossil record dating back more than 500 million years.
- Fish habitat means a place used by any fish at any stage at any time of the year.

- Fishes have difference in shape, size, eating quality, fighting ability, reproduction and growth but they all have a common characteristic, i.e. they all depend on habitat and the type of habitat may sometimes depend on their stage of life. The water in which fish live has to be the right type whether it is freshwater, estuarine or saltwater.

- Fish distribution is mainly divided into two major components:
  - Marine (58 %)
  - Freshwater (41%)

- Four main ecological divisions are recognized among the species of marine fishes:
  i. Epipelagic fishes
  ii. Deep pelagic fishes
     i. Water column dwelling fishes are subdivided into
        - Mesopelagic fishes and
        - Deeper dwelling bathypelagic fishes.
  iii. Deep benthic fishes.
  iv. Littoral or continental shelf species

- The maximum diversity of marine fish species is in tropical waters.
- Distribution of inshore marine fishes is into four major marine regions (order of decreasing biodiversity)

  (i) Indo-West Pacific
  (ii) Western Atlantic
  (iii) Eastern Pacific
  (iv) Eastern Atlantic.
- Continents or large expanses of open ocean separate these regions from each other and been subdivided into different units by different authors

- Freshwater fishes are classified according to water temperature in which they survive.as the water temperature affects amount of oxygen present.
    - **Coldwater**: fish species that survive in the coldest temperature (10-16^{o}C).Common coldwater fish include brook trout, rainbow trout, and brown trout.

    - **Cool water**: fishes that prefer temperature between (16–27 °C). Common cool water species include muskellunge, northern pike, walleye, and yellow perch.

    - **Warm water:** fish species can survive in a wide range of conditions, preferring a water temperature around 27 °C.

- In most fishes all individuals live in fresh water or marine water.But some species are diadromous i.e. live part of their lives in rivers and lakes and part in oceans. These are

    1) Anadromous: spawning in freshwater but spending much of their time in the sea.
    2) Catadromous: spawning in the oceans but returning to freshwater.

1.7 TERMINAL QUESTIONS AND ANSWERS:

1. What is classification? Explain the importance of classification in fisheries.
2. Write fish classification by Berg.
3. Give a brief account of classification by Nelson up to Order level.
4. Explain the habit and habitat of fishes with example.
5. Give a brief account on fish distribution.

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UNIT 2: INTEGUMENT AND EXOSKETETON

CONTENTS:

2.1 OBJECTIVES

After studying this module, you shall be able to learn and understand:

(i) About the cells of the epidermis

(ii) Modification of epidermis

(iii) Functions of integument

(iv) Types of scales and their importance

(v) Types of chromatophores and their significance

2.2 INTRODUCTION

The body of a fish is covered externally by integument or skin to protect it from injury and infections. Other than protection the integument performs various functions like, respiratory, excretory and osmoregularity functions also. Skin is also the primary means through which an organism interacts with its environment. Some specialised organs like phosphorescent organs, poison glands and electric organs are present in the integument as an adaptation to suit the environmental conditions of the fish.

The layers of fish skin, comprising the epidermis, dermis and subcutis.

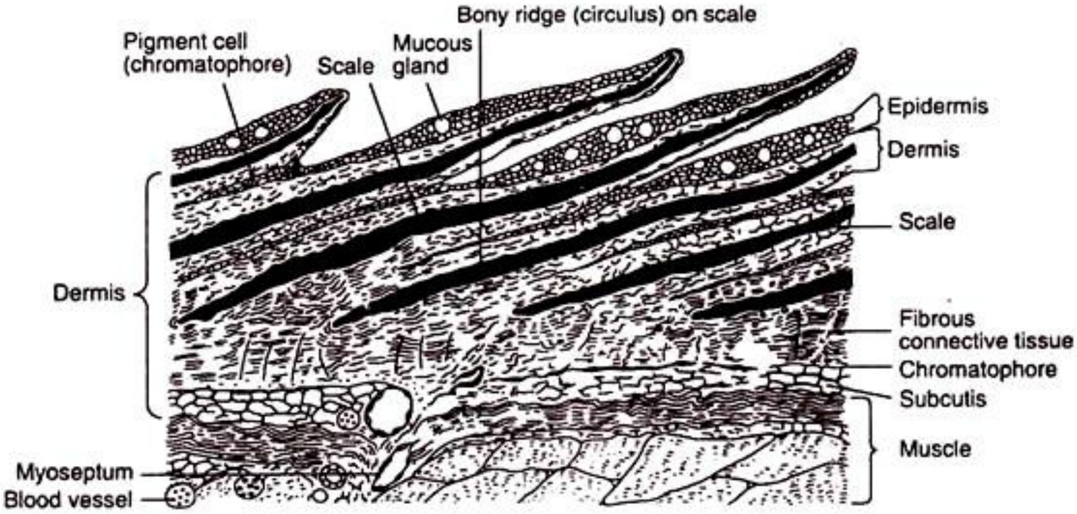

Fig.2.1: Section of Fish Skin (Source: General Biology supply House)

2.3 EPIDERMIS AND DERMIS

The Epidermis is the outer layer which is ectodermal in origin and it is composed of several layers of cells of various shapes. These cells are called epithelial cells. The thickness of the epidermis varies with species, age, size and, often, stage of the reproductive cycle. The epithelial cells of the epidermis made of a basal layer, a middile layer and a layer of superficial cells.

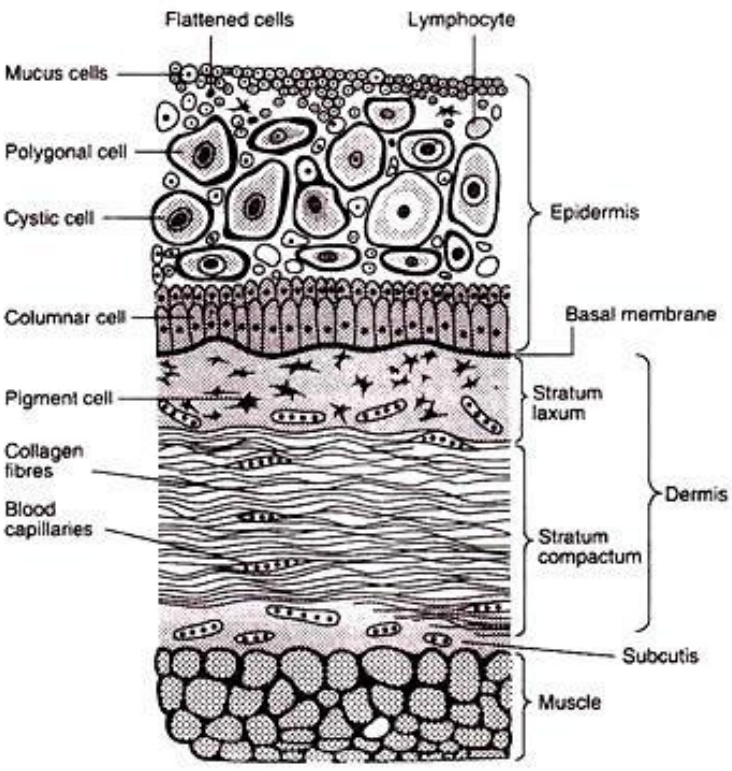

Fig. 2.2: V.S. of Fish Skin

EPITHELIAL CELLS

- The deepest layers of the epithelial cells are columnar or cuboidal cells with round or elongated nucleus. These cells are arranged in a single row forming the basal layer. The cells divide mitotically and give rise to new cells to replace the outer worn out cells.
- The cells of the middle layer are polygonal in shape with round nucleus.
- The outer layer (superficial) cells may be rectangular, columnar or cubodial in shape with basal nucleus. In many species of the fish tese are secretory in nature. They have secretory vesicles and their contents release to the exterior. Their contents form an extracellular cuticular coat, which has been called cuticle or glycocalyx by different authors.

TYPES OF THE EPITHELIAL CELLS

Mucous Cells: The epidermis of fish contains large number of mucous cells. These are unicellular glands, which open at the surface of the skin by minute pores. The glands may be flask shaped or goblet shape or sac like or tubular extending to the dermis. The mucous glands secrete slippery mucous, which contain a lipoprotein, known as mucin. The slimy mucus reduces friction on fish while swimming in the water. Regular secretion of mucous wash away micro-organism and irritants, which may cause disease if they are accumulated on fish skin. In some fishes, mucous is used for chemical communication. Some species like *Macropodus*, *Gasterosteus*, *Betta* etc. use their sticky mucus for preparation of nest for laying eggs. In *Protopterus* and *Lepidosiren,* the mucus forms a cocoon-like structure around the body to survive during aestivation.

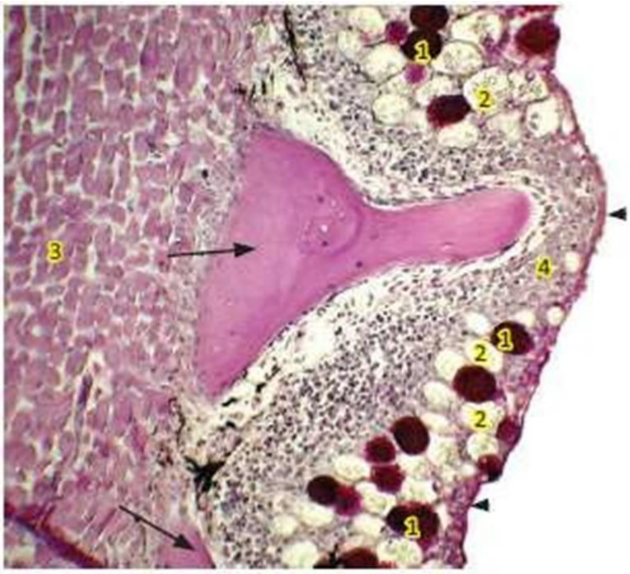

Fig.2.3: This micrograph illustrates the thick epidermis of a young specimen. This stratified layer contains numerous mucous cells filled with secretion (magenta- 1) as well as other ones (unstained -2) having secreted their mucus to form the mucous coat (arrowheads)

Club Cells: These are large cells and may be uninucleate or multinucleate. These are also known as "Alarm substance cells". It produces pheromone which initiates alarm reactions when percieved by olfactory organs of other fishes of the school. They are present in the middle of epidermis do not open to the surface of epithelium. Their numbers vary in different species of fish.

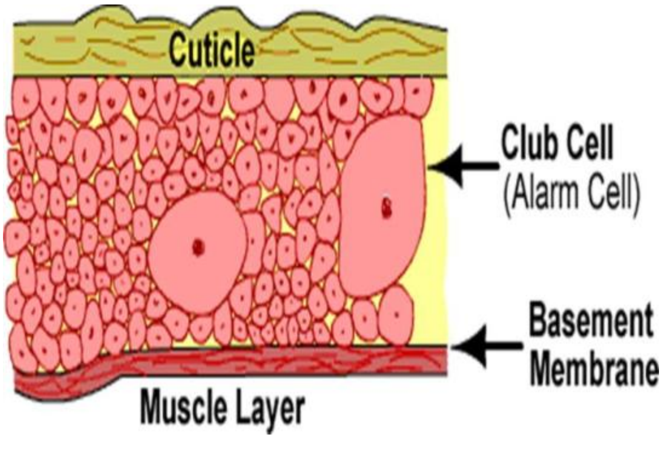

Fig.2.4: Club Cells

Poison Glands: Glandular cells of epidermis are modified into poison glands. These glands secrete poisonous substance to protect themselves from the enemy for defence. They are also used for offence as well. The poison glands are generally present at the base of certain structures like sting, spine of dorsal fin and tooth. Poison glands open at the tip of these structures to inject poison by penetration into the prey. The most common example is the stingray, which is provided with venomous caudal sting. Similarly, Chimaeras possess venom glands in spine of the dorsal fin. The poison glands are present in the grooves of spines of dorsal, pelvic and anal fins of the Scorpion fish (Scorpionidae). In Sturgeon fish (Acanthuridae), the poison glands are found at each side of the caudal peduncle.

Photophores: In most of the marine fishes, special multicellular glands are developed from basal layer of epidermis. The photophores are special gland cells of the epidermis. These glands are absent in fresh water fishes. These glands are deeply rooted into dermis and produce light. The photophores are found only in deep sea fishes.

Sacciform Cells: These are sac like unicellular glands in the epidermis of several species of fish. The nucleus is present in the basal part and these cells release protenaceous content. The cells present in the whole epidermis and may open to the exterior by a pore. Their secretion keeps the skin moist and helps in cutaneous respiration.

Other cells: Other than these cells epidermis of marine fish contain special cells are called ionocytes or chloride cells. These cells are excretory in nature. The fish epidermis also have various types of lymphocytes, granulocytes and chromatophores found freely in the intercellular spaces. The Lymphocytes are generally found in between the basal layer cells. Chromophores containing pigment granules of various types and the responsible for colour change.

Fish epidermis consists of various sensory receptors such as taste buds, ampullary organs, epithelial sensory cells and free nerve ending. These are found all over the body surfaces in several species of fishes.

DERMIS

The dermis is made of connective tissue, blood vessels and nerves. It can be divided into a thin layer of loose connective tissue, known as **stratum spongiosum** and a lower dense thick layer, the **stratum compactum**. The dermis is richly supplied by blood vessels, so it provides nourishment to the epidermis.

FUNCTIONS OF THE INTEGUMENT

• It support and protect soft tissues against abrasion, microbes. Mucous glands secrete copious mucous which forms a thick slimy layer all over the body and protect it from parasite, fungi and bacteria.

• The mucous lubricates the body of fish so as to reduce the friction in water enabling the fish to swim with greater speed.

• The mucous helps in repair and healing of the wounds of fish.

• Some fishes like *Betta, Gasterosteus* and *Macropodus* use their mucous for preparing the nest.

• Integument receives the external stimuli like, heat, cold, chemical change in water quality etc.

• It helps the fish to regulate the exchange of water and ions between the body fluids and external medium.

• It helps in heat regulation.

• It helps in cutaneous respiration. In some fishes like *Anguilla* and *Periopthalamus,* integument acts as an accessory respiratory organ. In these fishes the dermis becomes highly vascular.

• Scales, plates, spines etc. are the derivatives of integument and protect the body of fish.

• Poison gland of scorpion fish and toad fish are the modification of mucous gland and are useful organ of offence and defence.

• In the deep sea lantern fishes, the epidermal glands are modified into photophores to produce light.

• The colour of fish is due the presence of chromatophores in the dermis.

• Epidermal contains club cells secretes chemicals called pheromones which are "alarm substances" and warm other fish of the danger or enemy.

2.4 SCALES AND THEIR MODIFICATIONS

Scales form an exoskeleton in fishes but some fishes are "naked" devoid of scales, e.g., freshwater catfish. Scales are derivatives of mesenchymal cells of dermis. Certain species exhibit an intermediate condition that are generally naked but possess scales on restricted areas. Such condition is found in paddlefish (*Polydon*), in which scales are present in region of throat, pectoral and base of tail. In some fishes, scales are modified into teeth, bony armour plates (Sea horse) and spiny stings (sting ray). In fresh water eel (*Anguilla*), scales are very small and so deeply embedded that the fish appears to be naked.

Fig.2.5: Fossil of a primitive rayfin with ganoid scales (Courtesy: Xocolatl, Wikkipedia)

TYPE OF SCALES IN FISHES

There are few type of scales based on their structure and shape. The different types of scales are often characteristics of the species.

On the basis of shape, scales are of four types:

(i) Plate like or placoid scales, which develop from epidermis and dermis and commonly found in Elasmobranches.

(ii) Non-placoid scales, which develop from the dermis. These scales are following deifferent types:

a) Cosmoid Scales found in *Latemeria*.

b) Ganoid scales, common among gars and sturgeons.

c) Cycloid scales found in Burbot and soft-rayed fishes

d) Ctenoid scales, characteristics of spiny-rayed bony fishes (Acanthopterygii).

The Cycloid and ctenoid scales are also known as bony ridge scales.

PLACOID SCALES

Placoid scales are present in sharks and other Elasmobranches. They are small dermal denticles that remain embedded in the skin. Each scale consists of two parts: (i) an upper part, known as ectodermal cap or spine. Outer most covering of the spine is made of enamel, like substance, known as vitrodentine, it is hard and transparent, similar to human tooth.

The inner layer is the dentine that encloses a pulp cavity follows the vitreodentine. (ii) The lower part of placoid scale is a disc-like basal plate, which is embedded in dermis with cap or spine projecting out through epidermis. The basal plate has a small aperture through which blood vessels and nerves enter into pulp cavity. The placoid scales are modified in jaw teeth in sharks; in spines in dorsal fins; in *Squalus* (spiny dogfish); in sting in the stingrays and in saw teeth in the *Pristis*.

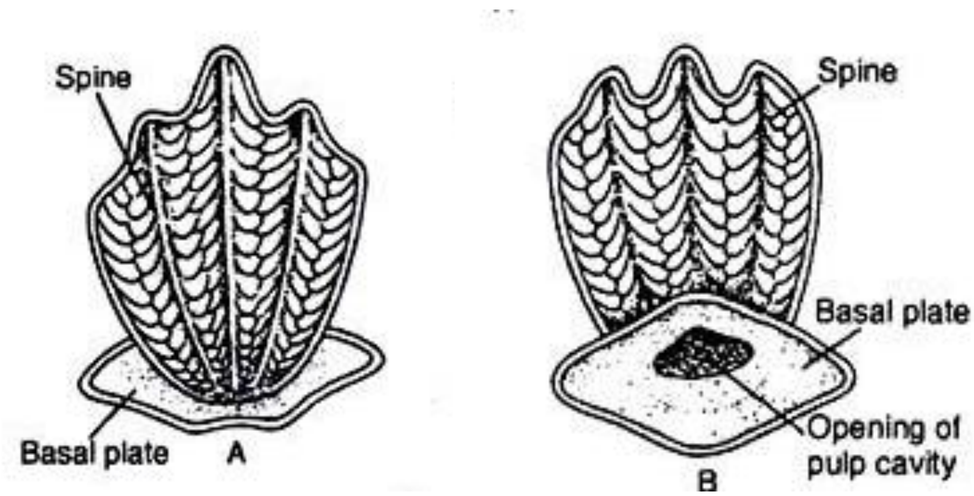

Fig.2.6: Placoid Scale: A. Dorsal View and B. Ventral View

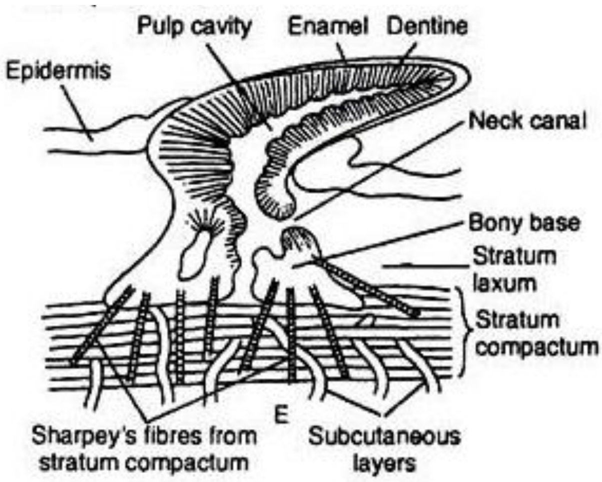

Fig.2.7: Digrammatic sectional view of Integument and the Placoid Scale Embedded in it

The placoid scales do not overlap each other and are closely arranged in the skin. Like the teeth of vertebrates, they are partly dermal and partly epidermal in origin and resemble teeth in basic structure.

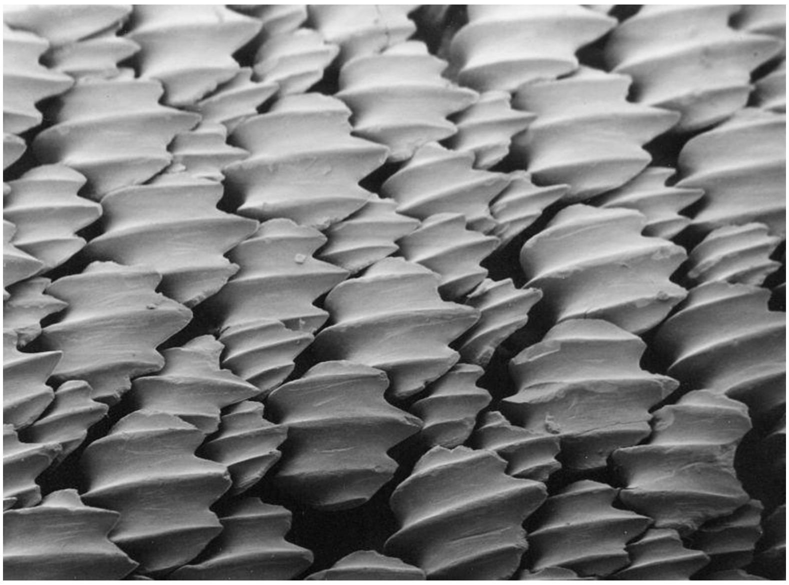

Fig.2.8: Placoid scales (Dermal denticles) of a lemon shark viewed through a scanning electron microscope (Courtsey: Pascal Deynat/Odontobase, Wikipedia)

DEVELOPMENT OF PLACOID SCALE

Just below the stratum germinativum, the placoid scale first appears as small aggregations of dermal cells. These dermal cells grow upwards into an arched structure or papilla and pushes the stratum germinativum. The cells of stratum germinativum of this region become glandular and act as enamel organ.

After sometime the projecting structure differentiates into a spine and a basal plate. The outer cells of the papilla, known as odontoblasts, secrete dentine around the papilla, while the central cells do not calcify and constitute the pulp. The vitreodentine to form a cap over the spine, gradually envelopes the spine of the scale.

The basal plate is secreted by the mesenchymal cells of the dermis. These cells secrete hard cement-like substance to cover the basal plate. Finally, the spine erupts from the cells of epidermis and projects out, while the basal plate lies embedded in the dermis.

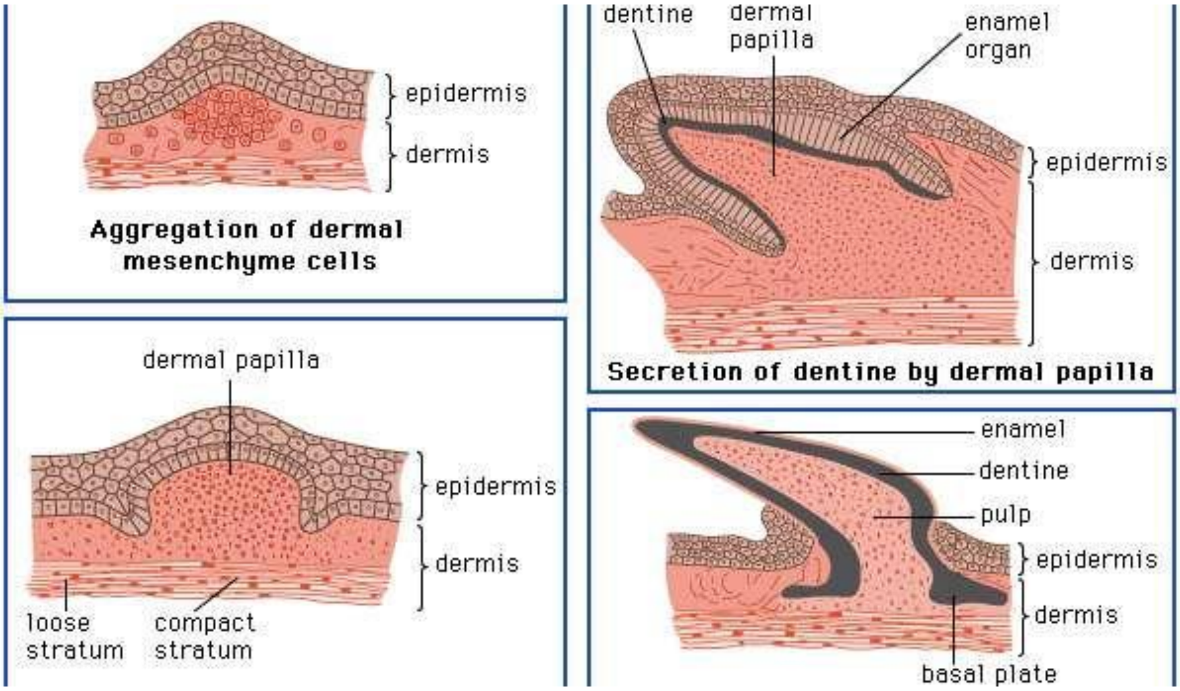

Fig. 2.9: Development of Placoid Scales

COSMOID SCALE

The cosmoid scales were found in the extinct crossopterygii and Dipnoi. In the extant fishes they are found in living *Latimaria* (crossopterygii) and extant Dipnoi. In Dipnoi, the cosmoid scales are highly modified and appear like cycloid scale. The cosmoid scale is a plate-like structure and consists of three layers. An outermost layer is known as vitreodentine. The vitreodentine thin, hard and enamel like substance. The middle layer is made up of hard non-cellular and a characteristic material, called cosmine and is provided with many branching tubules and chambers. The innermost layer is composed of vascularized perforated bony substance, called isopedine. These types of scales grow at the edges from beneath by addition of new isopedine material.

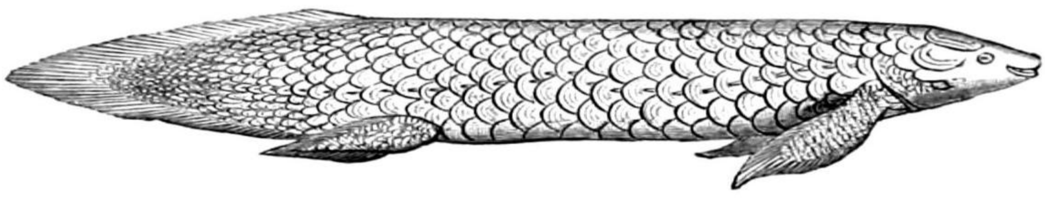

Fig.2.10: Extinct Australian lung fish (Courtesy: W H Flower)

Fig.2.11: Cosmoid Scale (Extinct Crossopterygian)

GANOID SCALE

The ganoid scales are thick, heavy and rhomboid. The outer layer of the scale is made up of hard inorganic substance called ganoine. The middle layer is formed of cosmine-like layer provided with many branching tubules. Bony isopedine is the innermost layer. These scales grow at the edges as well as grow at the surface. The growth takes place by the addition of new layers of isopedine.

The ganoid scale is best found in the *Polypterus* and *Lepidosteius*. In these fishes ganoid scales are rhombic plate-like, fitting edge to edge and invest the entire body. In *Acipencer*, the ganoid scales are modified into large bony scutes, arranged into five rows.

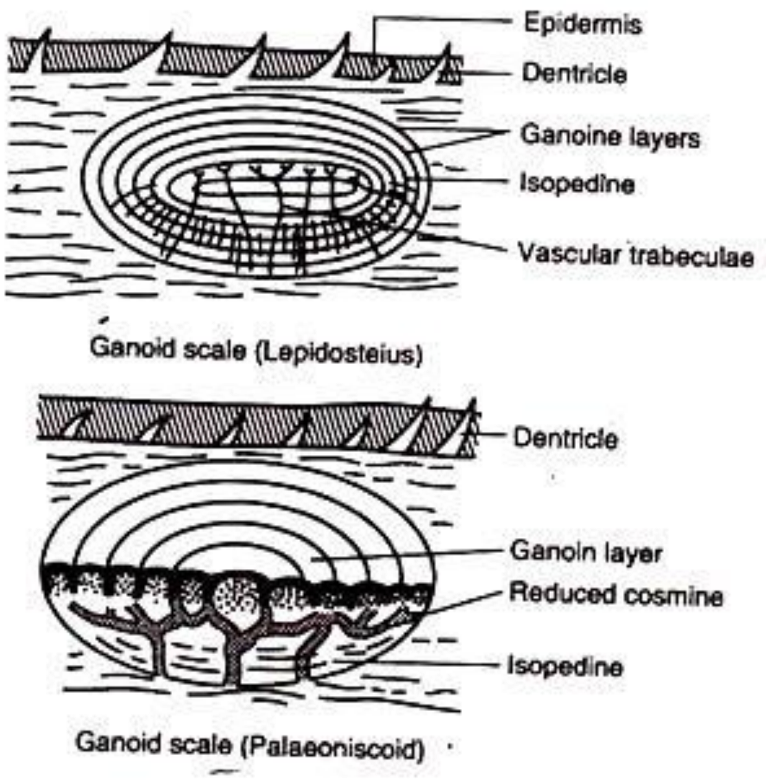

Fig.2.12: Ganoid Scale (Lepidosteius)

BONY-RIDGE SCALE

Bony ridges characterize the bony fishes, Osteichthyes. Due to the absence of dense enamel and dentinal layers these scales are semitransparent and thin. There are of two types of bony ridge scales: cycloid and ctenoid scales. The outer surface of these scales has bony ridges that alternate with groove-like depressions. The ridges are arranged in the form of concentric rings. The inner part of the scale is composed of fibrous connective tissue. The central zone of scale is known as focus of the scale. During the development, focus appears first and lies in the central position. When growth of scales takes place in anterior or posterior parts, it causes shifting of the focus anteriorly or posteriorly, respectively. Later the groves radiate from the focus towards the margin of the scales.

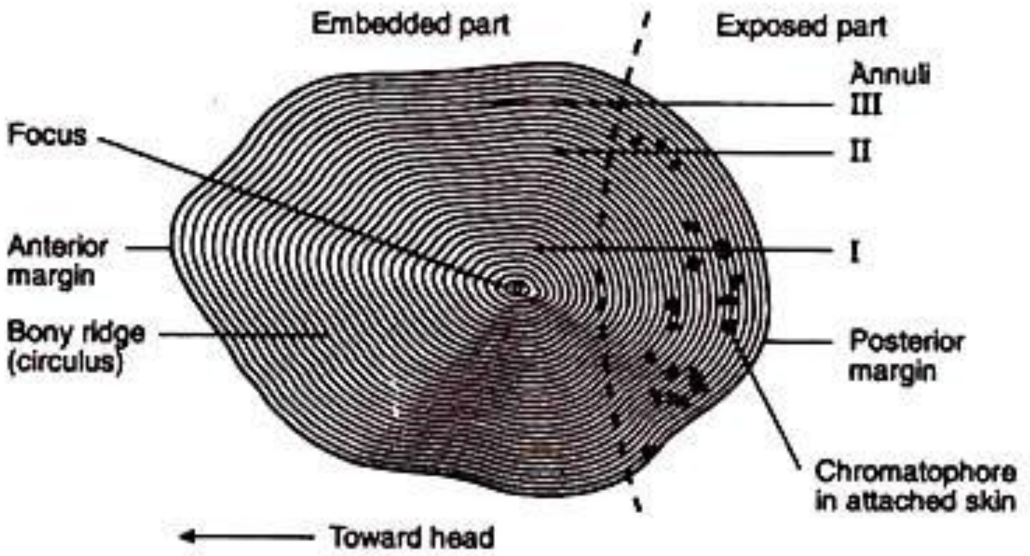

Fig.2.13: Bony Ridge Scale of Cycloid Type

CTENOID SCALE

They have characteristic teeth at its posterior part. Ctenoid scales are found in spiny-rayed teleost eg. Sunfish, Perches etc. They are arranged obliquely in such a manner that the posterior end of one scale overlaps the anterior edge of the scale present behind. The chromatophores are present at the posterior part of these scales.

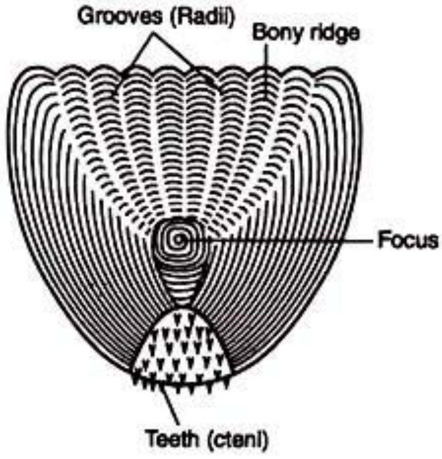

Fig.2.14: Ctenoid Scale

DEVELOPMENT OF BONY RIDGES

The bony ridge scales show their appearance from dermis as small accumulation of cells at the caudal peduncle and then gradually spread from there. Soon a focus is formed in the centre of the accumulation of cells. Later on, ridges or circulus are formed at the surface of growing edge of scale. The deepest part of the scale, the basal plate is made up of successive layers of parallel fibres. Some calcification of this fibrillar plate occurs to strengthen the scale.

2.5 USES OF SCALES

Following are the uses of fishes:

1. Scales play very important role in the identification and classification of fish.

2. Scales are used in calculating the age of fishes and rate of their growth. The age of fish could be determined by measuring space in annual rings of the scales.

3. In some species like Atlantic *salmon*, the scales exhibit the presence of spawning marks on them. These marks indicate how many times the fish has spawned and the time of first spawning also.

4. Scales provide important information about extinct fishes and are useful in identifying food habits of piscivorous animals.

MODIFICATIONS OF SCALES

1. In Sharks, the placoid scales modified into teeth and help in catching the prey. In the saw fish, *Pristis*, the teeth of the saw are modified scales.

2. The sturgeon fish has rows of ganoid scales enlarged into scute-like armour plates.

Fig.2.15 : Sturgeon Fish (Courtesy: Duane Raver/U.S. Fish and Wildlife Service)

3. In the Surgeonfish, *Acanthurus*, the sharp cutting blades at the base of the tail are modified scale.

Fig.2.16: Acanthurus dussumieri (Courtesy: Irán V. Shaw)

4. In *Teratodon* (Puffer Fish) and *Diodon* (Porcupine fish), the scales are enlarges and modified into spines. It covers the whole body for protection.

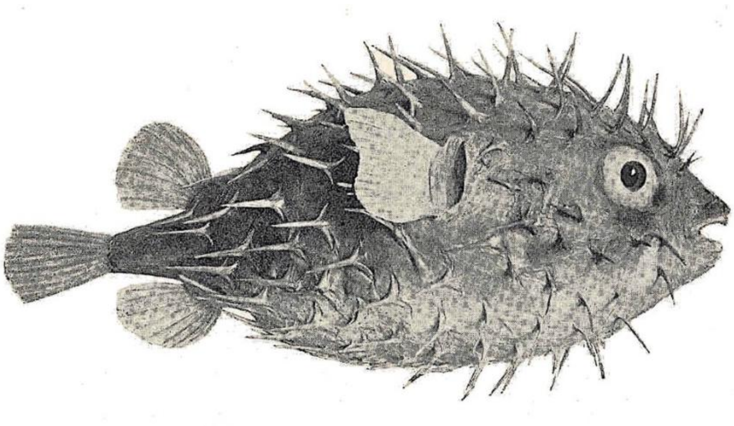

Fig.2.17: Porcupine fish have scales modified into spines (Courtesy: Edgar Ravenswood Waite)

5. The protective bony rings surrounding the body of sea horse and pipe fish are also formed by scales.

Fig.2.18: Hippocampus (Courtesy :C. Achilles - Day, Francis (1878) The Fishes of India. Volume 2)

6. The coffer fish (*Ostracion*) is protected by a rigid protective box formed by articulating bony plates formed by the scales.

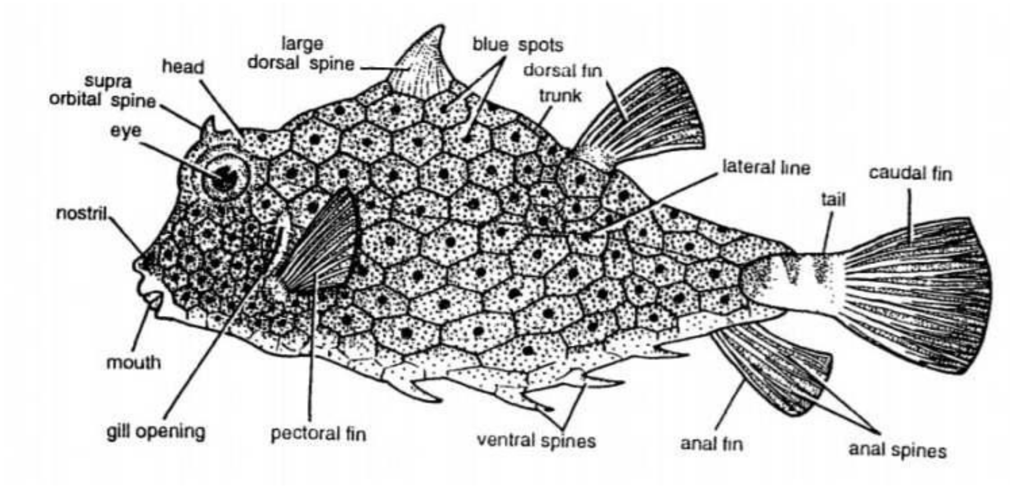

Fig.2.19: Ostracion

2.6 PIGMENTATION & COLOURATION IN FISHES

Colourations in fishes is due to the presence of various kinds of pigments in the integument several species are brightly coloured exhibiting beautiful characteristic patter white other have a uniform shade . Some of the beautifully colour fish water fishes species are the *Carassious* (gold fish) *Colisa*, *Botia* and *Noemachelus*. In the live or freshly killed fishes the bright colour are seen. Colour in fish is due to presence of Chromatophore and iridocytes. The chromatophore and iridocytes are present in the integument above and below the scales. Their number varies in different species. The distribution of chromatophores in body parts of fish is depending on the species type.

CHROMATOPHORES

The chromatophores are branched cell lying in the dermis. They are known as Erythrophores (red /orange), Xanthophore (yellow) and Melanophores (Black). They contain various types as pigment such as Carotenoid (Yellow, Red) Melanin (Black), Purine (white or silvery), and Flavins (yellow). Other colours like the blue, green and brown are due to the mixing of three kinds of chromatophore in various proportion. The yellow, red and orange pigments are taken through the food while the black pigment is formed due to the breakdown of the amino acid (tyrosine). The distribution of chromatophores is maximum at the dorsal surface. The colour of fish is due to the distribution of chromatophores on the body and presence of pigments in it.

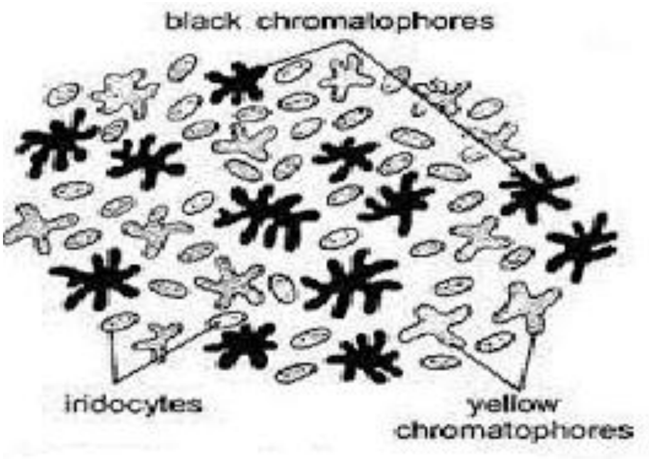

Fig.2.20: Chromatophores of Fish Skin

IRIDOCYTES

The iridocytes are also known as "Mirror cell". They are specialized cells and have great reflecting power. The iridocytes contain guanine which is white apaque or crystalline material and occur in the form of crystals, granules, platelets. The iridocyte give white or silvery colour to the body. The number of irridiocytes more on the ventral side than the dorsal side.

COLOUR CHANGE IN FISHES

To adjust to the surrounding environment the fishes change their colouring pattern. The change in colour of the fish is due to concentration of the pigment towards the centres of the cells or their dispersion towards the peryphery. There are two kinds of colour change:

(i) A temporary Change: A Temperorary change in colour pattern is done by the rearrangement of pigment granules.

(ii) A Semipermanent Change: When the total number of chromatophores slowly increases or decrease, it will bring the semipermanent change in the colouring pattern of fish. For example when a fish moves to a darker environment and has to stay there for some time, a slow change in colour taken place. The time required to bring the semipermanent change in colour pattern will depend on habitat, species, age, sex health of the fish.

Movement of pigments in the chromatophore to bring about change in colour is coordinated through hormone and nerves.

NEURAL CONTROL

In several species the chromatophore are innervated nerves. The neurones produced chemichal messenger called neurohumors to active them. There are two types of nerves fibre having opposite effects. One fibre secretes neurohumors which cause pigment dispersion, while the other fibre secretes neurohumors which bring about their concentration. In *Phoxinus phoxinus*, nerves stimulation bring about aggregation of melanin, and melanin dispersing nerve fibers is also present in this species. Neural control brings about a rapid change in the colour. But control through hormones is relative as slow process.

HORMONAL CONTROL

In many species of fish, pitutary gland controls the migration of pigment granules in chromatophore. It has been observed that after removal of pituitary gland (hypophysectomy) the colour of the fishes becomes light. If pitutary extract is injected into the body of the fish the colouration of these fishes resorted temporarily. However some species do not respond to hypophysectomy or pituitary injection, because their melanophores are not under the control of hormone. Melanophore stimulating hormone (M.S.H) is secreted by the pars intermedia of the hypophysis (Pituitary gland). M.S.H bring about concentration so the pigment in melanohormone causing the skin to become darker. In the absence of M.S.H.the skin of fish becomes lighter. Hypothalamus controls the pituitary gland by this way it is also controlling the M.S.H. Adrenaline hormone also have the positive effect on M.S.H. Thyroxine produced by the thyroid gland is also reports influence the colour of the skin in some species. In the Eel *Anguilla anguilla*, colour change in under neural as well as hormonal control. When treated with adrenaline, pigment concentration has been observed in the eels.

Fishes have been divided into three groups depending upon the degree of neural control over its melanophores.

DEGREE OF NEURAL CONTROL

1. Aneuronic : Whose melanophores are not innervated by nerves (are not under the control of neurons). E.g. Skates, dogfish etc.

2. Mononeuronic: In which the chromatophores are innervted by single fibres which stimulates the pigments to dispersing in the center. E.g. *Mustelus squalus*

3. Dineuronic: In which the chromatophores are connected with both dispersing and concentrating fibres. E.g. Teleost

2.7 SIGNIFICANCE

1. Protection (Camouflage): Many species of fish resemble the colour of the surroundings and are able to change colour so as to perfectly match the area thus concealing their presence. Some major forms of camouflage in fish include protective resemblance, disruptive coloration, countershading, mirror-siding, and transparency. For example, the location of sea horse and pipefish is difficult to find out due to their protective colouration. Coral reef fishes resemble the coral head and cannot be detected easily.

2. Protective resemblance: Protective resemblance is blending in, or resembling an object that is not of interest to a predator. One example is the juvenile *Platax orbicularis* that resembles a leaf floating in the water. Another example is the *Hippocampus bargibanti* that resembles the coral it hooks to.

Fig.2.21: Platax orbicularis (Courtesy: Alexander Vasenin, Wikipedia)

It is a mean to catch the prey by disguise (Concealment and Disguise)

3. It is a mean to advertise the presence of the fish (for Sea Recognition).

2.8 SUMMARY

The body of a fish is covered externally by integument or skin to protect it from injury and infections. Other than protection the integument performs various functions like, respiratory, excretory and osmoregularity functions also. The layers of fish skin, comprising the epidermis, dermis and subcutis. The Epidermis is the outer layer which is ectodermal in origin and it is composed of several layers of cells of various shapes. These cells are called epithelial cells. The thickness of the epidermis varies with species, age, size and, often, stage of the reproductive cycle. The epithelial cells of the epidermis made of a basal layer, a middile layer and a layer of superficial cells. The dermis is made of connective tissue, blood vessels and nerves. It can be divided into a thin layer of loose connective tissue, known as stratum spongiosum and a lower dense thick layer, the stratum compactum. The dermis is richly supplied by blood vessels, so it provides nourishment to the epidermis. Scales form an exoskeleton in fishes but some fishes are “naked” devoid of scales, e.g., freshwater catfish. Scales are derivatives of mesenchymal cells of dermis. Certain species exhibit an intermediate condition that are generally naked but possess scales on restricted areas. Such condition is found in paddlefish (*Polydon*), in which scales are present in region of throat, pectoral and base of tail. In some fishes, scales are modified into teeth, bony armour plates (Sea horse) and spiny stings (sting ray). In fresh water eel (*Anguilla*), scales are very small and so deeply embedded that the fish appears to be naked.

Placoid scales are present in sharks and other Elasmobranches. They are small dermal denticles that remain embedded in the skin. Each scale consists of two parts: (i) an upper part, known as ectodermal cap or spine. Outer most covering of the spine is made of enamel, like substance, known as vitrodentine, it is hard and transparent, similar to human tooth. The inner layer is the dentine that encloses a pulp cavity follows the vitreodentine. (ii) The lower part of placoid scale is a disc-like basal plate, which is embedded in dermis with cap or spine projecting out through epidermis. The basal plate has a small aperture through which blood vessels and nerves enter into pulp cavity. The placoid scales are modified in jaw teeth in sharks; in spines in dorsal fins; in *Squalus* (spiny dogfish); in sting in the stingrays and in saw teeth in the *Pristis*.

The cosmoid scales were found in the extinct crossopterygii and Dipnoi. In the extant fishes they are found in living *Latimaria* (crossopterygii) and extant Dipnoi. In Dipnoi, the cosmoid scales are highly modified and appear like cycloid scale. The cosmoid scale is a plate-like structure and consists of three layers. An outermost layer is known as vitreodentine. The vitreodentine thin, hard and enamel like substance. The middle layer is made up of hard non-cellular and a characteristic material, called cosmine and is provided with many branching tubules and chambers. The innermost layer is composed of vascularized perforated bony substance, called isopedine. These types of scales grow at the edges from beneath by addition of new isopedine material.

Ctenoid scales are found in spiny-rayed teleost eg. Sunfish, Perches etc. They are arranged obliquely in such a manner that the posterior end of one scale overlaps the anterior edge of the scale present behind. The chromatophores are present at the posterior part of these scales.

Colourations in fishes is due to the presence of various kinds of pigments in the integument several species are brightly coloured exhibiting beautiful characteristic patter white other have a uniform shade . Some of the beautifully colour fish water fishes species are the *Carassious* (gold fish) *Colisa*, *Botia* and *Noemachelus*. In the live or freshly killed fishes the bright colour are seen. Colour in fish is due to presence of Chromatophore and iridocytes. The chromatophore and iridocytes are present in the integument above and below the scales. Their number varies in different species. The distribution of chromatophores in body parts of fish is depending on the species type.

To adjust to the surrounding environment the fishes change their colouring pattern. The change in colour of the fish is due to concentration of the pigment towards the centres of the cells or their dispersion towards the peryphery. There are two kinds of colour change:

(i) A temporary Change: A Temperorary change in colour pattern is done by the rearrangement of pigment granules.

(ii) A Semipermanent Change: When the total number of chromatophores slowly increases or decrease, it will bring the semipermanent change in the colouring pattern of fish. Movement of pigments in the chromatophore to bring about change in colour is coordinated through hormone and nerves.

2.9 TERMINAL QUESTIONS AND ANSWERS

Q.1 Describe colouration, its significance with mechanism of colour change in teleost fishes.

Q.2 Describe the structure and functions of skin of fishes.

Q.3 Explain the types of scales found in fishes and write their uses also.

Q.4 Write essay on the development of placoid scale.

Q5 Explain the types of cells found in integument of fish.

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UNIT 3: FINS AND SWIM BLADDER

CONTENT

3.1 OBJECTIVES:

The study of this unit will let the students understand the following:

- Origin and evolution of fins
- Types and structure of fins
- Modifications and functions of fins
- Swim bladder
- Composition of swim bladder gas, its secretion and maintenance
- Structure and functions of swim bladder

3.2 INTRODUCTION

The primary locomotory organs of fish are their fins, which come in two varieties: middle or unpaired fins and paired fins. Three fins make up the median fins: a dorsal on the back, an anal behind the ventral side, and a caudal at the end of the tail. The pectorals and pelvics, which correspond to the fore and hind limbs of terrestrial animals, are represented by the paired fins. Skeletal rods known as the radials and dermal fin rays support both the median and paired fins. The fin rays of teleosts are bony structures with branches and joints called lepidotrichia. A fin is a little part or limb that is joined to a bigger body or structure.

Fins are characteristic anatomical features composed of bony spines or rays protruding from the body of a fish. They are enclosed with skin and joined together either in a webbed fashion, as seen in most bony fish, or similar to a flipper, as seen in sharks. Apart from the tail or caudal fin, fish fins have no direct connection with the spine and are supported only by muscles. Their principal function is to help the fish swim.

Fins located in different places on the fish serve different purposes such as moving forward, turning, keeping an upright position or stopping. Most fish use fins when swimming, flying fish use pectoral fins for gliding, and frogfish use them for crawling. Fins can also be used for other purposes; male sharks and mosquito fish use a modified fin to deliver sperm, thresher sharks use their caudal fin to stun prey, reef stonefish have spines in their dorsal fins that inject venom, anglerfish use the first spine of their dorsal fin like a fishing rod to lure prey, and triggerfish avoid predators by squeezing into coral crevices and using spines in their fins to lock themselves in place.

Swim bladder, also called air bladder, flexibility organ overcome by most bony fish. In greater part of fishes a swim bladder is lies among the alimentary canal below and the kidneys and vertebral column above. Air bladder is absent in elasmobranchs.

Swim bladder contains gas (usually oxygen) and functions as a hydrostatic organ, enabling the fish to maintain its deepness without floating upward or sinking. It also serves as a resonating chamber to creator receives sound. In some species the swim bladder contains oil instead of gas. In certain primitive fish it functions as a lung or respiratory aid instead of a hydrostatic organ. The swim bladder is not present in some bottom-dwelling and deep-sea bony fish (teleosts) and in all cartilaginous fish (sharks, skates, and rays).

The swim-bladder occupies- the same location as the lungs of higher vertebrates and is regarded as homologous to the lungs. It differs from the lungs of higher forms mostly in origin and blood supply.

The swim bladder arises from the dorsal wall of the gut and gets the blood supply regularly from the dorsal aorta, whereas the vertebrate lung originates from the ventral wall of the pharynx and receives blood from the sixth aortic arch.

Every bony fish has a swim bladder, which typically serves as an organ of hydrostatic pressure. The swim bladder in fishes guides the entire group along an evolutionary channel from an early stage when it is a very little cellular extension from the gut.

3.3 ORIGIN AND EVOLUTION OF FINS

Mainly two types of fins are developed in fishes: Unpaired or median fins – they include dorsal fin on middle of the back and anal fins along belly behind, Caudal fin at the hinder end of the fish. Paired fins are pectoral and pelvic fins.

These fins were not present in ancestral forms. Later are forced to conclude that the paired appendages of vertebrates have no genetic connection with those of invertebrates but have arisen independently as vertebrates' novelties but rarely present in ancient *Ostracodermes.*

Four theories have been put forward for the origin of the paired fins:

1) Gill arch Theory

2) External gill theory

3) Lateral fins fold theory

4) Ostracoderm theory

Gill arch Theory

According to this theory the gill arches are the source of the paired fins and their girdles. The pectoral and pelvic girdles were formed from the two pairs of gill arches, and the fin skeleton was created from their gill rays. This theory was based on the supposition that early ganthostomes had gill arches that extended further behind than they do now. Based on this theory, fin direction has currently been clearly dorso-ventral, and both the pectoral and pelvic fins were located quite near to one another behind the skull. However, the migration, or moving backwards, of the pelvic fins accounts for their current position.

This theory objected by a large number of considerations:

i) It offers no explanation of the participation of a large number of muscle segments, in the formation of fins.

ii) In ontogeny, paired fins never take appearance as a dorsoventral fold. On the contrary it always arises as more or less extended longitudinal ridges.

iii) The position of pelvic fins was attributed by *Gagenbaur* to their backward migration but neither in the primitive fishes nor in the early fossils. This is observed.

iv) Presence of vertical muscle buds in front of pelvic fin fold in ontogeny has been supposed to indicate backward migration. Since such buds are also found behind same fins. This can hardly be so.

v) In the skeleton, fins were derived from the gill rays, the muscle supply should come from the lateral gill plates but not from the myotomes.

vi) The position of limb girdles is lined outside the blood vessels and nerves and coelom is the reverse of what it should be if derived from gill arches.

vii) The theory does not explain the remarkable resemblance borne by the paired fins to the unpaired fins. So all the objections impart deadly against to gill arch theory.

2) External gill theory

It is an alternative to the gill arch theory that *Grahm Kerr* proposed, and it states that the paired fins came from the external gills found on crossopterygians, lung fish, and urodele amphibians.

Indirect evidence suggests that each gill arch contains external gills. Furthermore, it is claimed that gill arches stretched beyond the branchial limit of existing vertebrates, tail ward. Due to their shape and musculature in urodeles, such external gill arches are regarded as powerful organs of support and movement.

Besides the external gills occur at a certain time and for special purpose of only respiration. Except for a superficial resemblance to the highly specialized and reduced limbs of "*Dipneumnous"* external gills differ from paired fins in every important respect.

3) Lateral fins fold theory

Balfour, Tracher, and Mioast advanced the updated version of this hypothesis. According to this theory, the paired fins have originated from longitudinal folds and are fundamentally the same as the unpaired fins in nature. Their appicals have developed by hardening the fin fold and girdle by extending the radial basis inward. The continuity of the pectoral and pelvic fins is not a fundamental component of the idea. The recognition that the longitudinal fins that gave rise to the paired fins were comparable to those that had produced the median fins is crucial. It's possible that from the very beginning, the paired fins were discontinuous and differentiated into pectoral and pelvic fins.

There are many facts in support of the continuity of pectoral and pelvic fins, like great extensions of muscle band areas and of collector nerves both in front and behind the fins. The concentration of fin elements and shortening of fin rays and frequent presence of the great number of muscle bands in early stages than incorporated in the fins. Very remarkable in this connection is the production of an uninterrupted series of muscle bands from the pectoral to pelvic fin in some fishes such as *Syllium* and *Lophies.*

Every trunk segments of the body is capable of producing paired fin elements muscular, nervous and skeletal. The potentiality is, however, expressed by segments along restricted areas for instance in *Scyllium* 2 to 19 segments contribute to pectoral fin and 25 to 35 pelvic fins. The motor components of the special nerves always faithful to its myotomes throughout the changes which may take place in the ontogeny. The number of spinal nerves sending motor fibers to the nerve plexus of the fin indicates the number of muscle segments that are incorporated in the fin.

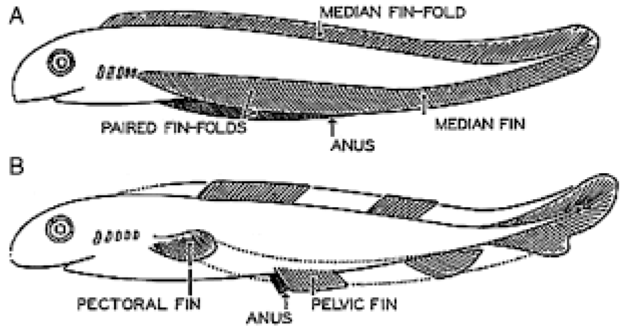

Fig.3.1 Organ of fins Balfour's Fin Fold Theory

(Source: https://anatomypubs.onlinelibrary.wiley.com/doi/full/10.1002/dvdy.192)

Remaining to the above account this theory is widey accepted and has its confirmation from palaeontology and embryology.

4) The Ostracoderm Theory

According to this idea that the appearance of paired appendages goes to the Ostracoderms which may have been the remote ostracoderms which have been the remote ostracoderms had a cephalothorax with a shield of horny plates. Certain forms possessed lateral fleshy lobes projecting froms lateral body wall. Rhese fleshy lobes may have become pectoral fins and the pectoral girdle may have developed as in growth from the basal portion of these fins. The dermal bones of the pectoral girdle may have originated from the bony plates of thoracic shields.

Another group of Ostracoderms had a paired row of dermal spines on the ventral side of the body, not unlike the spines of Acanthodian sharks. The spines may have been in use in clinging to a rapidly moveing fresh water streams. Loss of and relation of spines rxcept for those in the pectoral and pelvic regions might account for the origin of paired appendages from the ostracoderm ancestor with the growth of the muscles from the myotomes into the bases of these spiny fins and their movement may have been accomplished.

The anatomical, embryological and fossil evidences show that the fin fold theory is inadequate because it arose from the median and paired spines of ostracoderm.

The paired fins frequently changed their position of body in the course of phylogeny. This variation is even found in individuals of same species and effects both in partition with regard to each other and to the body as a whole. The proposer of gill arch theory held that changes of position and due to the migration of limb elements from one place to another which is not confirmed by embryology or palacontology.

So, three other explanations have been offered for this:

i) Theory of intercalation

ii) Theory of redivision

iii) Theory of progressive modification and transposition

i) Theory of intercalation

According to this theory of intercalation and excalation the shifting happened due to the segments having been dropped out or new segments adding up. It is supposed that the segments may be intercalated or excalated at any point in front within or behind in the fin and its plexus.

If such was the case there shold be joined growth and joines of reduction, their new segments appear and old disappear. But no such segments occur and 2 sets of fins, the median and paired shift independently. But the first dorsal is opposite to pectoral in lamina between the pectoral and pelvic, in *Alopecies* opposite pelvic in *Syllium* and behind pelvic in *Raja*. If the dorsal fin is homologous in four genera no addition and`no suppression of segments can account for this disposition. This and other objections have successfully adequated against this theory.

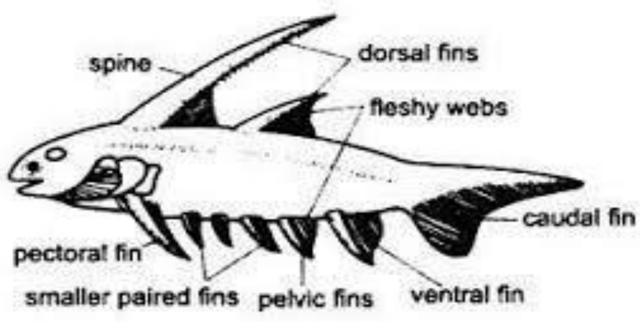

Fig.3.2 Fin Spine Theory

(Source:https://www.notesonzoology.com/phylum-chordata/fishes/fin-system-of-fishes-with-diagram-chordata-zoology/8041)

ii) Theory of redivision

According to this theory states that one individual organ is composed of 20 segments and other 19 segments. The difference according to this theory is not due to addition or substraction of a segment but due to the subdivision of the individual organ into 20,21 or 19 segments. On the bases of this theory no segments in the first case strictly corresponds to any segment in the other two. This theory offers on explanation and cannot be applied in any way better than the theory of intercalation.

iii) Theory of Progressive migration and Transposition

According to this theory by progressive growth in one direction and by corresponding reduction in the other, change of position takes place. By gradual growth a limb supplied with nerves may come. A limb plexus may be shifted without alternating its structure from one region to another by growth at one end accompanied by reduction at the other. The explanation is incomplete hormony with the findings of comparative anatomy and morphology.

3.3.1 TYPES OF FINS

Mainly two types of fins in fishes: Median or unpaired fins and Paired fins.

Median or unpaired fins: All fishes' median fins grow as a result of differentiation within an ongoing embryonic fin fold. A tissue fold that runs continuously along the back from the tip of the tail to the cloaca forms initially dorsally along the body during development. This condition is exhibited in lampreys and denotes a primordial state of the median fin. A succession of cartilaginous rods is then used to strengthen this fold. The formation of distinct dorsal, caudal, and anal fins in higher fishes results from the concentration of radials in specific regions and the degeneration of the fold in the spaces in between the fins. According to the ontogeny of the median fins in telesots, concentration is a critical developmental phase since these fins are essentially segmental structures in terms of their neurological, muscular, and skeletal components. The middle fins of sturgeons represent a primordial kind among modern bony fishes. A fleshy lobe with fin muscles enclosing the basal and radials is given on the dorsal and anal at their bases. The fleshy lobe at the base of the fin has vanished in all upper bony fish species, and the radials have been reduced to bone or cartilage nodules.

The dorsal, anal and caudal fins are unpaired and situated along the midline of the body. Cadual fin are: (i) Protocercal ii) Heterocercal iii) Homocercal

Paired fins: Paired fins were an early development in fish evolution that did not exist in the ancestors of vertebrates. Diverse kinds of fishes have a wide range of variation in the endoskeleton that supports the paired fins. The "archipterygium" is the term for the original, prehistoric state, which resembled Ceratodus' fins. It was given an anterior preaxial and a posterior post-axial set of radials attached to it, and it has a middle jointed axis that articulates with the girdle. The size of the radials reduced as they approached the tip and were positioned on either side of the median axis. A biserial arrangement of the radials is what this is. Only *Ceratodus* has this sort of "biserial archipterygium," which was present in the Devonian Crossopterygii and caused the fin to have an acutely lobate shape. The 'pleuroarchic' or uniserial kind of skeleton present in teleosts is thought to have originated from the archipterygii through shortening of the median axis and reduction in the post axial radials that eventually disappeared completely.

This particular variety of "biserial archipterygium" is only seen in Ceratodus, and it existed in the Devonian Crossopterygii. It caused the fin to have an acutely lobate shape. The 'pleuroarchic' or uniserial kind of skeleton present in teleosts may have developed from the archipterygii by shortening the median axis and reducing the post axial radials, which eventually disappeared entirely.

The pectoral and pelvic fins are paired.

3.3.2 STRUCTURE

Fins are one of the most unique features of a fish and they have several different forms.Fins are two types median and **paired**. Median fins are single in number which runs down the mid line of the body. In fishes, median fins are dorsal, anal and caudal fins while paired fins are pectoral and pelvic. Fins help to swim and maintain the balance of the body. Fins also help to identify the fish species. Different types of median and paired fins are described below:

Dorsal Fin

The dorsal fins are situated on the back of the fish which help the fish in rapid turns or stops. It also helps the fish against undulating. The three different dorsal fins present in fish, such as proximal, central or middle, and distal dorsal fins. Some fish have two dorsal fins where the central and distal fins are combined together.

In boxfish, ocean sunfish and puffer fish use their dorsal fin in combination with their anal fin for impulsion.

Gymnarchus uses only its dorsal fin for propulsion.

Pelvic Fin

A pair of pelvic fins is present in fishes, which are situated ventrally below and behind the pectoral fins. In some fishes, they are located in front of the pectoral fins (Cod family). Pelvic fin helps in strength and slowing down the fish. Generally, fish use pelvic fins for moving upwards and downwards in the water.

Anal fin

The Anal fin is located on the ventral side just behind the anus. It supports the dorsal fin and stabilizes the fish during swimming and controls the undulating motion.

Pectoral Fin

Pectoral fins are situated on both sides usually just behind the operculum. It is homologous to the tetrapod's forelimbs. It provides supports throughout swimming. It creates dynamic lifting force and also helps the fish to turn left or right.

Adipose Fin

Adipose fin soft fins and located between the dorsal and caudal fins. They usually very near to the caudal fin. It is mostly found in catfishes. This type of fin helps to find the way fish in rough water.

Caudal Fin

The caudal fin is the primary appendage which is used for locomotion in many fishes. The caudal fin is also known as tail fin or a median fin which is usually homocercal or heterocercal. Generally, it is a vertically extended structure which is located at the caudal end of the body. The base of the caudal fin is known as caudal peduncle with strong swimming muscles. In general, caudal fin acts like a propeller while the caudal peduncle functions as a motor.

The caudal fin has two lobes such as dorsal epichordal and ventral hypochordal lobe which are supported by the modified last three caudal vertebrae. The shape of the caudal fin may vary in different species from rounded to pointed, notched, emarginated, truncated, etc. It is used to identify the fish species. Generally, fish use it for forwarding propulsion and speed.

The caudal fin differs from the dorsal and anal fins the nature of its supporting skeleton and is of three main types:

Protocercal Caudal Fin

The most primitive type of caudal fin is called a protocercal fin. Here, the notochord, or spinal column, separates the caudal fin into two equal lobes, such as the upper lobe and lower lobe, at its straight hind end. In this instance, the lower lobe is referred to as the hypochordal or hypocaudal lobe, and the higher lobe is known as epichordal or epicaudal. In Depnoi, a secondarily symmetrical tail is described using the term "diphycercal," while all symmetrical tails are referred to as "protocercal." Amphioxus and Cyclostomata both contain it. The protocercal stage is where the coudal fin develops in all fish species.

Heterocercal Caudal Fin

The Chondrichthyes and several early bony fish have tails that are heterocercal (unequal). The notochord's rear end is twisted upward at this point and extends almost to the caudal fin's tip. The caudal fin is symmetrical both outwardly and internally because the ventral hypochordal lobe is significantly larger than the dorsal epichordal.

Homocercal Caudal Fin

The majority of upper bony fish have homocercal (equal) tails, which is their distinguishing feature. It features upper epichordal and lower hypochordal lobes, which appear to be symmetrical and equal in size. This tail is asymmetrical on the inside, and the vertebral column's hind end has been sharply compressed and bent upward. In this instance, the posterior limit of the fin is not touched by the end of the vertebral column. Numerous bony fishes have intermediate types, which are descended from the heterocercal type and are the homocercal type.

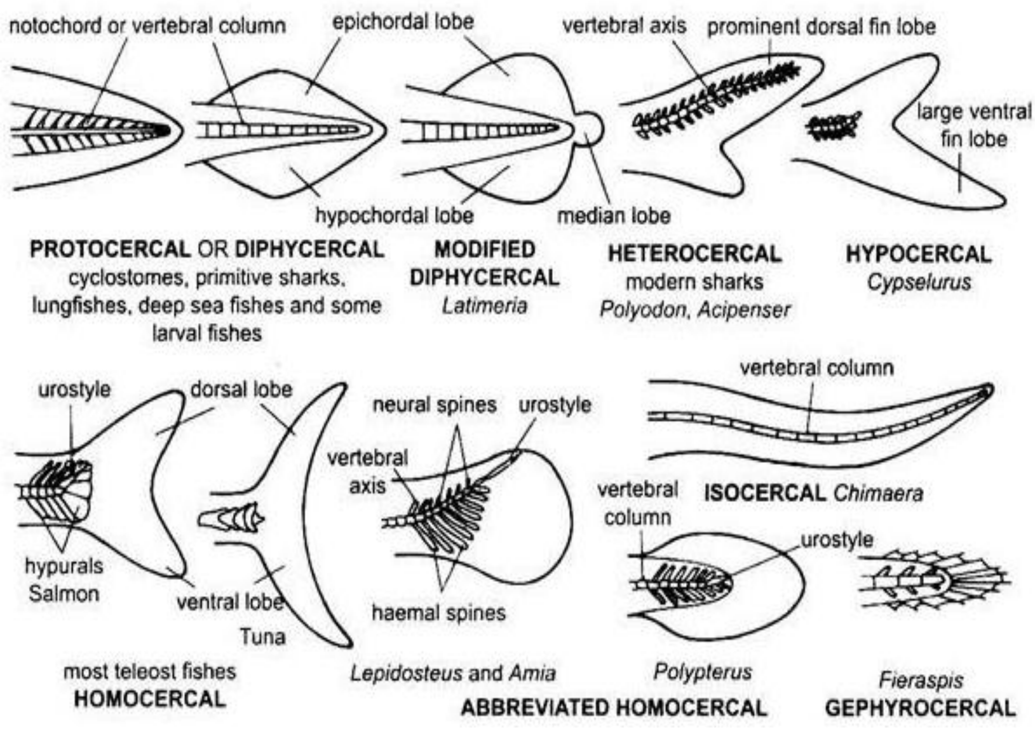

Fig. 3.3 Different types of caudal fins or tail in fishes

(Source: https://www.notesonzoology.com/phylum-chordata/fishes/fin-system)

3.3.3 MODIFICATIONS AND FUNCTIONS OF FINS

Many fishes have specific adapted types of caudal fins such as:

1. Isocercal or leptocercal
2. Internally symmetrical Caudal Fin
3. Pseudocercal Caudal Fin
4. Hypocercal Caudal Fin
5. Gephyrocercal Caudal Fin

1. **Leptocercal or Isocercal**

Some fish have a tapering caudal fin, and the balanced kind is referred to as isocercal or leptocercal. The spine of isocercal fins has a long, straight rod-like shape. The isocercal caudal fin is present in rat tails (Macruidae), Blennies (Blennidae), Eels (Anguilliformes), featherbacks (Notopteridae), and gymnarchids (Gymnarchidae), among other species.

2. Internally Symmetrical Caudal Fin

Where a few fin components are fused together, the caudal fin is compact in this case. They are found in cods (Order: Gadiformes).

3. Pseudo-caudal Caudal Fin

The pseudocaudal caudal fins are seen in the Dipnoi. In this instance, the dorsal and ventral elements grow ventrally before developing into fins.

4. Hypocercal Caudal Fin

The dorsal lobe of the caudal fin of the Hypocercal type is considerably larger than the ventral lobe, which is considerably more compact. It is also known as inverted heterocercal caudal fin. There are hypocercal type cadual fins in several early Agnathans. Where the lobe grows from the vertebra's upper surface in this instance, the vertebral axis abruptly bends downward.

5. Gephyrocercal Caudal Fin

A highly particular variety of caudal fin is the gephyrocercal caudal fin, commonly referred to as the bridge caudal fin. They frequently resemble isocercal fins, however the fins are simply remnants. Where the spinal column's hypurals are missing in this instance, the caudal lobe is diminished. The pearlfishes (Carpus), Flerasfer, and Orthagoriscus have these kinds of fins.

FUNCTIONS OF FINS

For various purposes fish use their fins. Some important functions of fins are described below:

Fish use their fins for a number of things. Some important functions of fins are described below:

1. Usually, a fish's pectoral fins aid in turning.
2. Some bony fish, including Cirrhitichthys, use their pectoral fins to assist them rest on the bottom or in reef environments.
3. Flying fish (Exocoetidae family) glide over the water by using their large pectoral fins.
4. Some bottom-dwelling fish, including threadfins (Polynemidae), have taste buds and touch receptors on their pectoral fins that assist them locate food.
5. Fish with pelvic fins float more steadily in the water.
6. Some fish, including clingfish (family Gobiesocidae), use their pelvic fins as sucking appendages to hold on to immobile things on the ocean floor.
7. The majority of bony fishes use their dorsal fin to shift their orientation quickly.
8. Dorsal fins function as a 'keel' to keep fish anchored in the water.
9. Some angelfishes in the phylum Lophiiformes use their dorsal fin as a lure to draw in prey.
10. Some fish (Echeneidae) use their modified dorsal fin as a sucking disc.
11. Gymnarchus niloticus, the African knife fish, uses its dorsal fin to create undulations in order to swim forward or backward.
12. The majority of bony fish use their caudal fins to propel themselves.

13. Fast swimmers, like tunas, are known to have lunate caudal fins. They use it to maintain a high pace for an extended period of time.

14. Anal fins contribute to stability and aid in reproduction in some bony fishes.

15. Sea robins travel along the substrate using their pelvic fin.

16. Some fish use their pelvic fins for gliding, such as Freshwater Butterflyfish (Pantodon buchholzi).

17. Sea Robins may float in the currents by using their pectoral fin.

3.4 SWIM BLADDER SPECIES

The gas bladder shows a number of structural modifications in various groups of bony fishes as following:

Chondrostei

In *Polypterus*, the gas bladder is of the most basic form. The bladder has two halves. It has an oval-shaped left lobe and a long, tubular right lobe. The two lobes join together at the anterior end to form an unpaired chamber that opens in the oesophagus on the ventral side. Internal sacculations are absent from the organ. The bladder's wall is a smooth surface. The bladder is ova shaped, its walls are smooth, and the glottis is a large entrance into the oesophagus in *Acipenser.*

Holostei

The gas bladder in *Lepidosteus* is an unpaired, long, elongated sac with a glottic opening into the oesophagus. Alveoli made of fibrous bands are built into the bladder wall. Each of the two rows of alveoli is further subdivided into sacculi. *Amia* has a much larger air bladder than *Lepidosteus*, and the alveoli on its wall are smaller but more numerous.

The ductus pneumaticus is quite short and the bladder is nearly directly attached to the oesophagus in the lower teleostomi described above. These fish lack the "Retia mirabilia" red bodies or red glands.

Dipnoi

The ventral side of the Dipnoi is equipped with a muscular vestibule that opens into the oesophagus. *Neoceratodus* has a single vestibule, while *Lepidosiren* and *Protopterus* have double vestibules. Alveoli in the bladder wall that may open into ducts leading to caecal sacculi (*Protopterus)* interact with the bladder's central chamber. The bladder is very vascular in all Dipnoi, although red bodies or red glands are not visible.

Teleostei

Despite being present in many teleosts, the gas bladder or swim bladder is completely lacking in certain species of fish, including the flat fishes (Pleuronectiformes), Giganturiformes, Saccopharyngiformes, Pleuronectiformes, Echeneiformes, Gobeisociformes, and Symbranchiformes. In various teleosts, the air bladder can have a variety of shapes, including tubular, fusiform, oval, heart-shaped, dumb-bell-shaped, and horse-shoe-shaped. It is separated into two intercommunicating chambers in the Cyprinidae. The bladder often rests unrestricted inside the abdominal cavity or may be firmly connected to the vertebral column by fibrous structures. The gas bladder may grow into the tail in the form of a pair of caeca in some species of Notopteridae, Sparidae, Carangidae, and Scombridae. The anterior chamber of the gas bladder is very small and is contained in a bone capsule in *Psillorhynchus* and *Nemacheilus,* two fish dwelling in torrential waters of the highlands, where the posterior chamber of the gas bladder has vanished. Fish that breathe air include *Heteropneustes fossilis* and *Clarias batrachus*; their air bladders are significantly smaller and enclosed in bone.

Many teleosts have caecal outgrowths that resemble fingers that sprout from the gas bladder. The majority of fish species with caecal appendages are vocal species. *Gadus* air bladder sprouts two caecal outgrowths that protrude into the front of the head. In *Otolithus,* two small tubular outgrowths from the bladder's anterolateral wall separate into sacs that face forward and backward, respectively. In the Scianidae family, *Carvina lobata* has a series of tubular caeca that extend from the lateral walls of the air bladder.

The gas bladder frequently has two or even three chambers that are separated by internal septa or partitions. In many fish, the bladder cavity is split into two compartments that communicate with one another by a transverse diaphragm that is pierced by an opening encircled by sphincter muscle. In *Notopterus,* the bladder's abdominal region is divided into two lateral chambers by a longitudinal wall. A T-shaped septum divides the bladder cavity *in Mystus seenhala.*

All teleosts are initially physostomous, although some of them develop physoclism as adults. The pneumatic duct often opens in the middle of the dorsal line, but in several species, it can also open to the right or left. The air bladder also opens to the outside at the hind end in a small number of clupeids (*Caranx, Clupea, Pellona, Sardinella),* however the Indian species *Hilsa* and *Gadusia* lack these secondary openings.

3.5 COMPOSITION OF SWIM BLADDER GAS, ITS SECRETION AND MAINTENANCE

It has been demonstrated by Biot (1807) and Morean (1876) that the swim-bladder primarily secretes oxygen. Additionally, nitrogen and a small amount of carbon dioxide are present. In general, various species have varied gas compositions. Nitrogen makes up the majority of the gas in the swim bladder of salmonids. Again, a mixture of oxygen and carbon dioxide makes up a large portion of the composition in many organisms.

The combination of gases in the bladder varies. In shallow water fish, the ratios closely approximate that of the atmosphere, while deep sea fish tend to have higher percentages of oxygen. For instance, the eel *Synaphobranchus* has been observed to have 75.1% oxygen, 20.5% nitrogen, 3.1% carbon dioxide, and 0.4% argon in its swim bladder.

3.6 STRUCTURE AND FUNCTIONS OF SWIM BLADDER

Basic Structure of Swim-Bladder

While gas absorption into the circulation occurs in the posterior portion of the physoclistous forms, the anterior part of the swim bladder, whether open or closed, is specialised for gas secretion. The posterior section is transformed into a "oval" in more specialised physoclisti like the Mugil, Balistes, and Gadus, whose opening is protected by a sphincter and dilated by muscles. The red body, also known as the red gland, is a tiny area in the anterior region that has developed a specialisation in gas secretion.

Syngnathidae species, specifically in a few of them. The gas bladder is closed and divided into two chambers in the Gadidae, Labridae, and Triglidae. The front chamber of these fish contains a gas gland that secretes gas, while the posterior chamber develops thin walls to allow for gas diffusion. However, the gas bladder is split into two chambers and possesses a pneumatic channel in the Cyprinidae. The gas gland in this location is restricted to the posterior chamber. The anterior swim bladder chamber of cyprinids has an auditory role, while the posterior chamber mostly has a hydrostatic purpose.

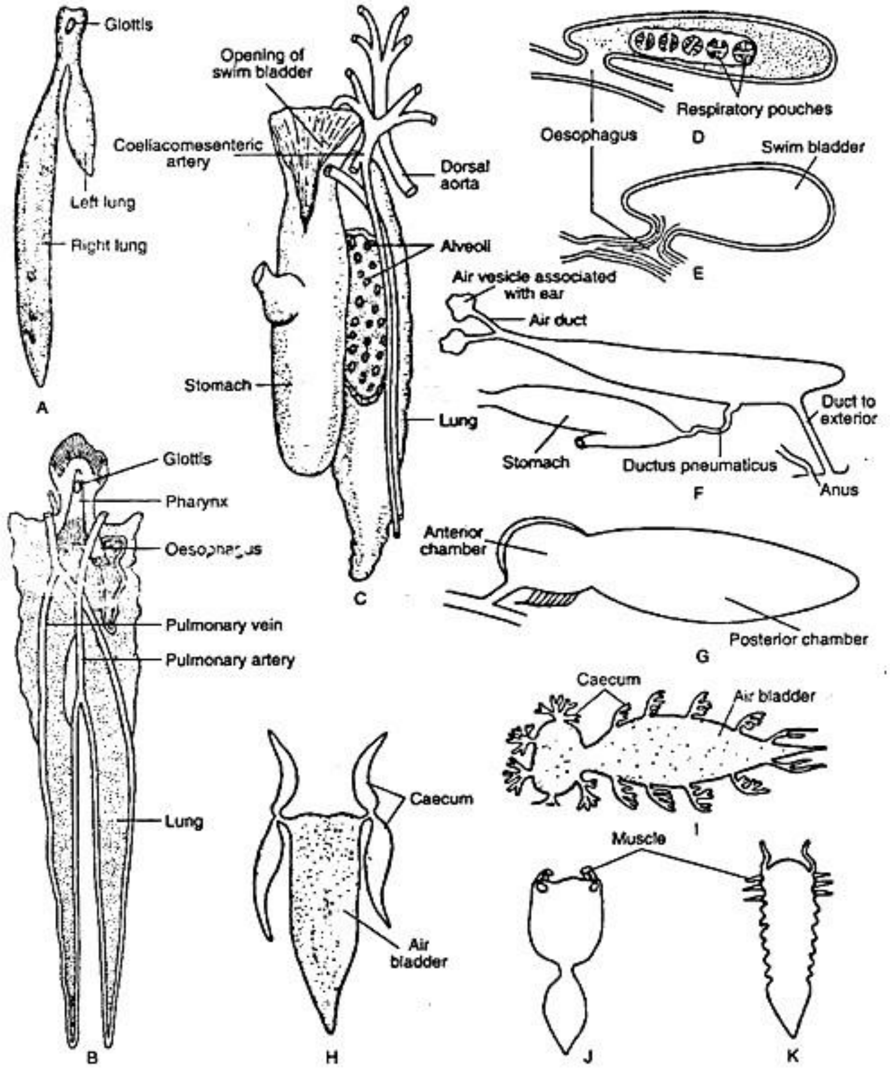

Fig. 3.5 Structure of swim bladder in fishes: (A) *Polypterus* (B) *Protopterus* (C) *Gymnarchus* (D) *Amia* and *Lepisosteus* (E) *Acipenser* (F) *Clupea harengus* (G*) Essox* (H)*Gadus* (I) *Otolithus* (J) *Corvina lobata* (K*) Pangassius*

(Source:https://www.notesonzoology.com/fish/swim-bladder-in-fishes-zoology/410)

According to histology, a cyprinid swim bladder's anterior chamber wall is made up of the following:

(1) The tunica externa is formed of dense, fibrous collagen.

(2) The submucosa, which is made up of loose connective tissue.

(3) A layer of dense smooth muscle fibres known as the muscularis mucosa.

(4) Lamina propria, which is made up of a thin layer of connective tissue, is the fourth layer.

(5) The epithelial cells in the innermost layer.

However, the internal epithilum of the swim bladder's posterior chamber can vary in height throughout the chamber. A glandular layer exists outside the smooth muscle layer and is made up of big, atypical cells with coarsely granulated cytoplasm. Blood capillaries from the rete mirabile, which is also located outside of the layer of muscles, provide abundant blood flow to the glandular layer. Additionally, the dustus communicans, which connects the two chambers, has dense layers of muscle supplied by nerve fibres. The muscles of the posterior chamber are thought to regulate the swim bladder's volume as well as the function of the gastric gland. The ductus communicans muscles may function as a sphincter.

The ductus pneumaticus, which connects the swim bladder to the oesophagus in lower teleosts (Chondrostie and Holostei), is either short and wide or longer and narrower depending on the species. Most of the gas that the swim bladder secretes is oxygen. A small amount of carbon dioxide and nitrogen are also present.

TYPES OF SWIM-BLADDER:

The swim-bladder in fishes can be divided into two major categories: Physostomus and Physoclistous kinds, depending on the presence of the duct (ductus pneumaticus) between the swim-bladder and the oesophagus. Older taxonomists divided the teleosts into the Physostomi and Physoclisti groups based on the health of the swim bladder. In eels, a transitional phase is seen.

A. Physostomous Condition:

The oesophagus gives rise to the swim bladder. The swim-bladder is referred to as physostomous type when the ductus pneumaticus is present between the swim-bladder and the oesophagus (Fig. 3.5A). The swim bladder is supplied by a conduit that emerges from the coeliacomesenteric artery, and the blood it produces is then transported to the heart via a vein that joins the hepatic portal vein. Dipnoans, soft-rayed teleosts, and bony fishes are all known to suffer from this ailment.

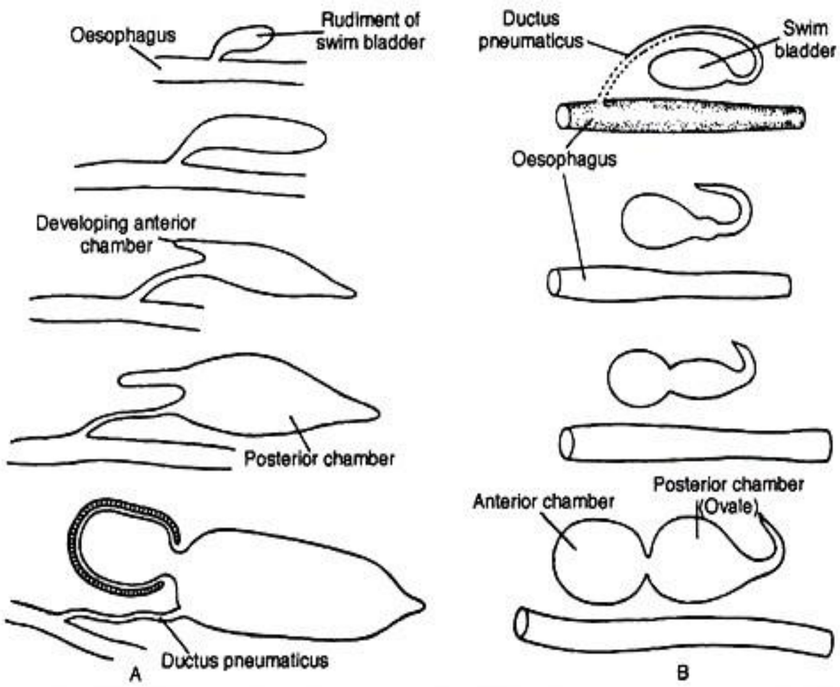

Fig.3.5 The derivation of the swim bladder of the fishes of the gut A. stages of formation of physostomous type of swim- bladder B. Stages of formation of the physoclistous type of swim bladder.
(source: https://www.notesonzoology.com/fish/swim-bladder-in-fishes-zoology/4108)

B. Physoclistous condition:

The ductus pneumaticus is either occluded or atrophied in this condition (Fig.3.5 B). Spiny-rayed fishes have this kind of swim bladder. A posterodorsal gas-absorbing area known as the ovale and an anteroventral secretory gas gland with retia mirabilia are present in this form of swim bladder.

The ductus pneumaticus, which is deteriorating, gives rise to the oval. The coeliacomesenteric artery, as well as arteries from the dorsal aorta, supply blood to the rete mirabilis of the gastric gland, the bladder's oval, and its walls. But there are two ways for the blood to return from the various areas of the swim bladder.

The hepatic portal vein returns blood from the gastric gland to the heart, while the posterior cardinal veins return blood from the rest of the bladder. The oval is innervated by sympathetic nerves, whereas the bladder, particularly the gas gland, receives lateral branches from the vagus. Some dipnoans suffer from this condition.

FUNCTIONS OF SWIM-BLADDER

The swim-bladder in fishes performs a variety of functions.

1. Hydrostatic Organ:

It serves as a hydrostatic organ in order to keep the fish's body weight in balance with the amount of water it expels. By altering the volume of gas content, it also helps to rebalance the body's position in relation to the environment.

In physostomous fish, the ductus pneumaticus is responsible for expelling gas from the swim bladder; however, in physoclistous fish, where the ductus pneumaticus is lacking, excess gas is eliminated through diffusion.

2. Swim-Bladder acts as Adjustable Float:

The fish may swim at any depth with the least amount of effort thanks to the swim-bladder's additional function as an adjustable float. The body of a fish has a higher specific gravity when it enjoys sinking. The swimblade enlarges and the specific gravity decreases as it ascends. A fish may maintain equilibrium at any level by making such adjustments.

3. Swim-Bladder Maintains Proper Centre of Gravity:

The swim bladder permits demonstrating a variety of movement by transferring the contained gas from one area of it to the other, helping to maintain the right centre of gravity.

4. Swim-Bladder helps in Respiration:

The swimbladder's respiratory function is very important. The oxygen produced in the bladder may act as a source of oxygen in many fish living in water with a noticeably low oxygen level. The swim bladder is transformed into the 'lung' in a small number of fish, particularly in dipnoans. The 'lung' has the ability to take in atmospheric air.

5. Swim-Bladder as Resonator:

It is believed that the swimbladder functions as a resonator. It amplifies the sound vibrations and sends them to the ear via the Weberian ossicles.

6. Production of Sound:

The swim bladder aids in sound generation. Numerous fish, including Doras, Platystoma, Malapterurus, and Trigla, can make a drumming, hissing, or grunting noise. The swimbladder's internal air circulation drives the vibration of the incomplete septa.

The incomplete septa located on the inner wall of the swimbladder vibrate as a result of the sound being produced. The movement of the swim-bladder's trapped air is what causes the vibrations.

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The incomplete septa located on the inner wall of the swim- bladder vibrate as a result of the sound being produced. The movement of the swim-bladder's trapped air is what causes the vibrations.

The compression of the swim-bladder's intrinsic and extrinsic muscles may also result in the production of sound. By compressing and obliquely expelling the trapped gas in the swimbladder, *Polypterus, Protopterus,* and *Lepidosiren* can make sound. The musculus sonorificus likely aids in compression in male Cynoscion.

3.7 SUMMARY

Fish have a fusiform shape. Its whole body is covered in scales. Pectoral fins and pelvic fins are the next structures to appear following the operculum. The dorsal fin is located on the dorsal surface, and the anal fin is located on the anus. The tail is made up of caudal fins. Fins and the tail are a fish's locomotory organs. Fin pairs include the pectorals and pelvic fins. The median fins consist of the dorsal, anal, and caudal fins. While the fins are helpful for swimming and balance, the tail is useful for changing directions. Fish may move by making use of their myomeres.

Swim bladders, often referred to as air bladders, are tough organs that are present in the majority of bony fish. The swim bladder is situated between the alimentary canal and spinal column below and the kidneys and vertebral column above in the majority of fish. This bladder is absent in elasmobranchs. It contains gas (typically oxygen) and acts as a hydrostatic organ, allowing the fish to maintain its depth without floating or sinking. Additionally, it serves as the producer's sound-receiving room. In certain animals, the swim bladder contains oil rather than gas. In some ape-like fish, it acts as a lung or respiratory support rather than a hydrostatic organ. All cartilaginous fish (sharks, skates, and rays) and some deep-sea and bottom-dwelling bony fish (teleosts) lack the swim bladder.

3.8 TERMINAL QUESTIONS AND ANSWERS

Multiple Choice Questions:

1. Swim bladder is present in

a) Trygon

b) Scoliodon

c) Labeo

d) Chimaera

2**.** In which of the following groups the operculum is present?

a) Polypterus

b) Holocephali

c) Hippocampus

d) Teleostomi

3. Air bladder is connected to intestine in which one of the following group of fish (physostomous fish)?

a) Anguilliformes

b) Syngnathiformes

c) Ophiocephaliformes

d) Perciformes

4. What is air bladder?

a) Swimming organ of amphibians

b) Hydrostatic or respiratory organ of teleost fishes

c) Larva of *Tenia solium*

d) Excretory organ of teleost fishes

5. Air bladder is present in

a) Dog fish

b) Hag fish

c) Flying fish

d) Electric fish

6. Air bladder in most fishes is a

a) Purely respiratory organ

b) Major respiratory organ associated with lung

c) Hydrostatic organ, as an outgrowth of alimentary canal

d) None of the above

7…………. have got well developed swim bladders

a) Sciaenids

b) Flying fishes

c) Half beaks

d) Whitebaits

8. In which of the following fish swim bladder is absent?

a) Bony fish

b) Silver fish

c) Cartilaginous fish

d) Cattle fish

9. Fins help the fishes to-----------in water.

a) Breath

b) Reproduce

c) Eat

d) Swim

Answers: 1.c), 2.d) 3.a), 4.b), 5.c), 6.c), 7.a, 8c), 9d)

Short Answer Question:

1. What is the role of swim bladder in fish?
2. What is used fins in fishes?
3. How many types of fins found in fishes.
4. What are the main functions of the tails and fins of a fish?

Long Answer Question:

1. Write about the structure and modifications of fins.
2. Write the functions of swim bladder.
3. Write origin and evolution of fins.
4. How many different swim bladders present in fish.

3.9 REFERENCES

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UNIT 4: LOCOMOTION

CONTENT

4.1 OBJECTIVES

The study of this unit will let the students understand the following:

- Locomotion by body movements
- Locomotion by fins and Tail
- Forces acting on the body for locomotion
- Types of locomotion

4.2 INTRODUCTION

Fishes are perfectly adapted for locomotion in the water. The body is spindle shaped, thicker in front than behind and is perfectly streamlined for movement through water. The body covered with a layer of mucus which reduces drag on it. Usually, the shape of the body is fusiform but variations occur when the fish becomes adapted to specific mode of life.

Fish swim by exert force beside the surrounding water. There are exceptions, except this is normally achieved by the fish contracting muscles on each side of its body in order to produce waves of flexion that journey the length of the body from nose to tail, usually getting larger as they go along. The vector forces exerted on the water by such movement cancel out laterally, but produce a net force backwards which in turn push the fish forward during the water. The majority of fishes produce force using lateral movements of their body and caudal fin, except many other species move mostly using their median and paired fins. The concluding group swims gradually, but can turn fast, as is required when living in coral reefs for example. But they cannot swim as fast as fish with their bodies and caudal fins. Some species have laterally compressed body as in the Clupeidae, others possess dorso-ventrally depressed body as the skates, rays and many cat fishes, whereas some are elongated and eel-like. Many fishes have a streamlined body and swim freely in open water. Fish locomotion is closely connected with habitat and ecological niche.

Fishes swim by the following methods:

(a) By alternate contraction and relaxation of the muscles of the body called the myomeres. Thus, during swimming the fish oscillates from side to side showing lateral undulations.

(b) By various movements of the fins.

(c) By rapid expulsion of water as jet the gill aperture

4.3 LOCOMOTION BY BODY MOVEMENTS

Fishes swim in water by body movements brought about by alternate expansion and contraction of the myomeres and by movements of the fins.

Locomotion, only by means of fin movements, takes place when slow progress is desired, but for rapid swimming, body movement is most important. During such active swimming, the paired fins serve balancing the body so that the fish remains in position and does not float with belly upwards. The dorsal and anal fins from dorsal and ventral keel which can be lowered or raised according to needs and give stability to the body.

In elongated type of fishes such as eel the locomotion is of anguilform type. The movement is initated by the contraction of first few myomere on one side, so that the anterior part of the body is thrown into a curve, which passes backward in a series of waves by alternate contraction and relaxation of the muscle segments on each side of the body. The movement is of meandering nature and the fish looks like a crawling snake. In this case the forward thrust is obtained entirely by the pressure of the fish body against the water and the caudal fin has little function in anguilliform type of movement. Hence the caudal fin is very much reduced or absent in eel-like fishes. Instead the hider part of the body is laterally compressed and the blade-like structure thus formed, serves to provide a large amount of thrust to the fish. Fishes that have long, laterally compressed body as the Ribbon-fishes (*Trichiurus)* also swim very actively by undulating movements of their body.

Usually fishes swim in a horizontal position but a few swim vertically as the sea- horse (*Hippocampus*) and the Needle fishes (Centriscidae). Other methods of locomotion, besides swimming, are jumping, burrowing, flying etc. Some fishes jump out of water with a considerable forc either to escape from an enemy or to clear an obstacle. Thus *Salmon, Mugil, Cyprinus, Megalops* (Tarpon*)* sail fish etc. are able to take a leap out of water. Some species like the Exocoetus have enlarged pectoral fins and glide like a parachute for some distance, after jumping out of water. The pelvics are also enlarged along with the pectoral in Cypselurus for gliding in air.

4.4 LOCOMOTION BY FINS AND TAIL

Fins are extend appendages present on the body of fishes and are the chief locomotory organs. There are two types of fins, unpaired or median and paired fins. The median fins include a dorsal on the mid axis of the body, an anal on the mid ventral side behind the vent and caudal at the end of the tail. Pectorals and pelvics are the paired fins corresponding to the fore and hind limbs of the terrestrial tetrapod vertebrates. Fins are supported by skeletal rods called the radials and dermal fin rays. In teleosts the fin rays are branched and jointed bony structures and are known as the lepidotrichia. The fins without fin rays called dipose fins (e.g. Mystus)

The tail and the caudal fin are the chief organs of locomotion in fishes. During swimming, the tail is lashed from side to side by alternate contraction and relaxation of the muscles on the opposite sides of the vertebral column. During such movements the tail is first bent to one side. This is called the non-effective or backstoke. By a stroke in the reverse direction, the tail is extended and straightened. This is the forward or effective stroke. By a rapid succession of these strokes to right and left sides alternately, the fish forces its way through the water.

When a fish wants to move forwards, the first action is the contraction of first few myomeres of the anterior end of the body on one side only, so that the head is bent sharply to one side. This is followed by alternate contraction and relaxation of the successive myomeres , first on one side on one side of the body and then of other, from head towards the tail and the curve of the body passes backwards. The fish thus shows undulating movements and its body during swimming is thrown into a 'S' shaped curve. The actual forward thrust is affected by the pressure of the tail of the fish against the surrounding water. This is the most common method of locomotion in fishes and is called the 'carangiform' type.

In the 'Ostraciform' as in the" trunk fish" the head and body is enclosed in a hard and rigid bony case and the tail with a fan like caudal fin projects behind. In such fishes, undulating movements of the body are not possible and the dorsal and the anal fins form the chief propelling agents for slow movements. Ripid swimming takes place by movements of the tail. The anguiliform, carangiform and the ostraciform are the three main types of locomotion in fishes, but many intermediate types are also found to suit different species.

Besides the body muscles, fins are also important organs of locomotion in fishes. Many fishes are able of moving slowly forwards by means of wave like movements of the fin itself. The caudal fin is moved mainly by the muscles of the tail. The dorsal and the anal fins may be used as organs of propulsion. A sequence of wave like movements are produced in these fins, similar to those in the body of an eel, and the fish slowly moves forwards. Some fish like the Globe fish (*Tetrodon*), Prorcupine fish (*Diodon*), Sea-horse (*Hippocampus*), swim mainly by the propelling action of their dorsal and anal fins. Of the paired fins, the pelvics serve mainly for stabilising the body, but the pectorals are often using for slow locomotion. The pectoral fins may also be used for steering. A backward stoke of one fin while the other is kept folded, will wheel the fish round to the opposite side. Due to ventral position of the mouth, a shark has to turn to one side for feeding and this is capable by down stroke of pectoral fins of one side.

Water expelled from the gill apertures during respiration, also helps in forward movement of the body. This method is useful to some species but not to others. When the fish is resting on the bottom the pectoral fins are in constant motion to counteract the forward thrust produced by the respiratory current.

Commonly fishes swim in a horizontal position but a few fishes swim vertically as the sea-horse (Hippocapus). Other methods of locomotion, besides swimming, are jumping, burrowing, flying etc. Some fishes jump out of water with a significant force either to escape from an enemy or to clear an obstacle. Thus, *Salmon, Mugil, Cyprinus, Megalops* (Tarpon) etc. are able to take a leap out of water. The pelvics are also enlarged along with the pectoral in *Cypselurus* for gliding in air.

A few species burrow into the mud, making use of their swimming movements for the porpose. Fishes like the eel move slowly on the bottom making use of the body muscles and fins. Some fishes like the frog fish (*Antennarius)*, toad fish (*Lophius)* etc. crawl on the bottom with the help of pectoral fins that are used like arms. The climbing perch (*Anabas)* can even climb up the trees with the help of its pectorals and operculum. The mud skipper (*Periopthalmus*) uses its pectoral fins which are curved at an angle like an elbow joint, for jumping over the land.

4.5 FORCES ACTING ON THE BODY FOR LOCOMOTION

Fish swim by exerting force alongside the surrounding water. There are exceptions, but this is usually achieved by the fish contracting muscles on each side of its body in order to produce waves of flexion that move the length of the body from nose to tail, generally receiving larger as they go along. The vector forces exerted on the water by such movement cancel out laterally, but produce a net force backwards which in rotate pushes the fish forward through the water. The majority of fishes produce thrust using lateral movements of their body and caudal fin, but many other species move mainly using their median and paired fins. The concluding group swims slowly, but can turn quickly, as is wanted when living in coral reefs for example. But they can't swim as fast as fish using their bodies and caudal fins.

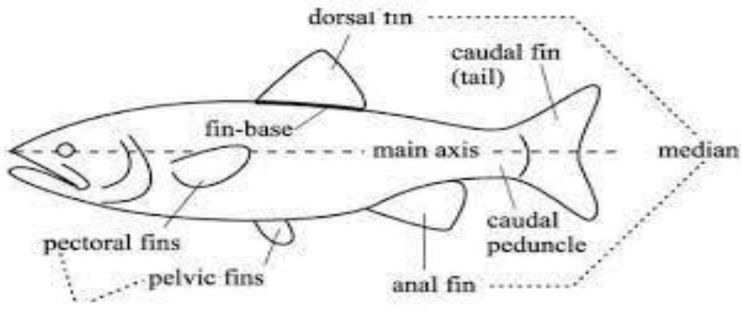

Fig. 4.1Locomotion in Fishes

(Source:https://www.google.com/search?q=locomotion+in+fishes&&tbm=isch&ved=)

LOCOMOTION IN SHARKS AND DOGFISHES (PLEUROTREMATA)

The body of Sharks and dogfishes are long and streamlined, with a heterocercal tail fin. Pectoral fins are situated in front of the centre of gravity that lies just below the dorsal fin. Larger upper lobe of the caudal fin produces raise force on tail due to which head pitches downward. Pitching power is countered by the pectoral fins which also function as elevators. Heterocercal tail fin helps elasmobranchs to swim next to the bottom of sea as the majority of the elasmobranchs are natural bottom dwellers.

Dorsal fins are antirolling procedure and they stop rolling of the body whereas the fishes turn right and left. Pelvic fins in cartilaginous fishes do not contribute to swimming or corresponding.

LOCOMOTION IN SKATES AND RAYS (HYPOTREMATA)

Similar to other elasmobranchs, rays also have heterocercal tail fin and two dorsal fins on the tail. But they have a doroventrally flattened body and enlarged pectoral fins are merged on the lateral margins of body. Pectoral fins can produce metachronal contractions and push the body forward. Rays being dorso-ventrally flattened body have no problem of rolling and thus dorsal fins are compact.

LOCOMOTION IN BONY FISHES

Majority of bony fishes have homocercal or diphycercal tail fin that produces a straight forward push on the body to counter sticky as well as force drag. Dorsal fin is foldable and can be extended whenever essential. Pectoral fins are located high and are used as brakes and for rotating right and left. Anteriorly located pelvic fins stop the upward lift of head whereas braking. Bony fishes too use operculum to throw out water to help in rapid rotating. Swim bladder maintains the fish stable at a given depth.

LOCOMOTION IN FLYING FISH

Flying fishes, remaining to their enlarged pectoral fins can move smoothly in air for significant distances. Caudal fin is hypocercal among enlarged lower lobe that helps to drag the tail down and keep head upwards whereas swimming so that they can swim upward quickly and jump out of water to move smoothly. Still pelvic fin is enlarged to give upward raise to the body.

LOCOMOTION IN SEA HORSE AND PIPE FISH

Sea horse and pipe fish have no fins excluding the single dorsal fin and thus this fin is used to push the body onward in a vertical position. Tail is prehensile to grasp on to the sea weeds and corals where these creatures remain disguised and prey upon planktons.

Various bony fishes such as *Amia* have long dorsal fin extending to almost the whole length of the back. This fin is able of undulation to push the body forward while swimming at slow speed. In the same way, *Notopterus* and *Wallago* have very long anal fin which almost continues up to the tail fin and is used to move forward the body.

The Trigger fish that can produce fast bursts of speed at short distances have very high caudal fin to increase the surface area. Dorsal fin and anal fins are also broad and located posteriorly close to the caudal fin to increase the aspect ratio of the posterior region so that a powerful push can be created to propel the body forward.

4.6 TYPES OF LOCOMOTION

The shape of body, three types of locomotion's in fishes:

Anguilliform locomotion

In anguilliform type of locomotion, the movement is of serpentine type and the fish looks like crawling snake. The forward thrust is generated by the pressure of the fish body against the water and the tail or caudal fin has little role in it. Hence, the caudal fin is reduced in eel-like fishes. Instead, the caudal region is laterally compressed, forming a blade-like structure and provides a large thrust of the body.

Eels *(Anguilla)* and cyclostomes having serpentine body swim by lateral undulation of the entire body that is caused by metachronal rhythm in the contraction of myotomes. This type of swimming is quite efficient at low speeds but consumes a lot of energy since the whole of the body is involved in locomotion.

Carangiform locomotion

In majority of fishes lateral undulation of body is restricted to the posterior one-third of body. Tail is lashed from side to side in such a way that it always has a backwardly facing component of push and caudal fin increases the area and the force of backward push of tail.

Ostraciform locomotion

This type of locomotion is found in box fishes and trunk fishes (family Ostraciidae) in which body is not flexible and hence cannot undergo lateral undulation. Therefore, only tail fin propels the body forward.

In the trunk fish (Ostracion), the head and body are enclosed in a rigid bony case, while the tail with caudal fin projects behind. Slow movement takes place by the dorsal and anal fins, while the lashing movements of the tail cause rapid swimming. This is called 'Ostraciform' locomotion.

Some species of fish seldom flex the body for swimming, and move forward by undulating movements of the median fins. Usually complete waves are seen along the fins. This is called 'balistiform' locomotion. Certain species as the catfish, parrot fish, surgeon fish do not oscillate the body or median fins. These fish use pectoral fins for locomotion and this is called 'labriform' swimming. Some species like the globe fish (Tetraodon), porcupine fish (Dindon) and the sea-horse (Hippocampus) swim with the help of dorsal and anal fins. Besides, pectoral fins are also used for slow movement. Water expelled from the gill aperture during respiration also helps in slow progression. When the fish is at rest, the pectoral fins are moving constantly to overcome the forward thrust produced by the respiratory current.

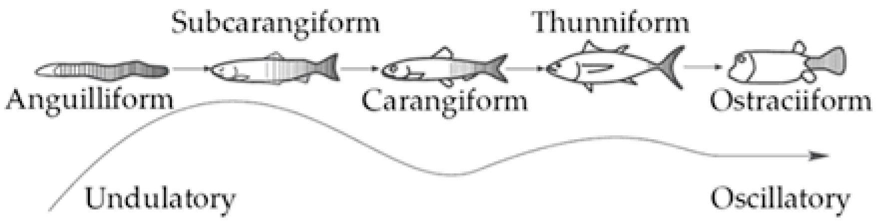

Fig. 4.2 Locomotion by body and fins

(Source: https://www.google.com/search?q=locomotion+in+fishes&&tbm=isch&ved=2ah)

4.7 SUMMARY

Fishes are perfectly adapted for locomotion in the water. The body is spindle shaped, thicker in front than behind and is perfectly streamlined for movement through water. The body covered with a layer of mucus which reduces drag on it. Usually, the shape of the body is fusiform but variations occur when the fish becomes adapted to specific mode of life.

Fish swim by exert force beside the surrounding water. The vector forces exerted on the water by such movement cancel out laterally, but produce a net force backwards which in turn push the fish forward during the water. The majority of fishes produce force using lateral movements of their body and caudal fin, except many other species move mostly using their median and paired fins. But they cannot swim as fast as fish with their bodies and caudal fins. Some species have laterally compressed body as in the Clupeidae, others possess dorso-ventrally depressed body as the skates, rays and many cat fishes, whereas some are elongated and eel-like. Many fishes have a streamlined body and swim freely in open water. Fishes swim in water mainly by two methods: a) By body movements brought about by alternate expansion and contraction of the myomeres, and b) By movements of the fins.

The shape of body, locomotion is fishes can be of three types. i) **Anguilliform,** seen in very flexible fishes with elongated body as the eel. ii) **Carangiform,** in which the undulations of the body are restricted to the caudal region, as in trout, rohu, mrigal, etc. iii) **Ostraciiform**, in which the body is inflexible being enclosed in a hard boxlike protective sheath, and locomotion is due to undulations of the caudal fin, as in Ostracion, Tetraodon, Diodon, etc.

Fish swim by exerting force beside the surrounding water. There are exceptions, but this is usually achieved by the fish contracting muscles on each side of its body in order to produce waves of flexion that move the length of the body from nose to tail, generally receiving larger as they go along. The vector forces exerted on the water by such movement cancel out laterally, but produce a net force backwards which in rotate pushes the fish forward through the water. The majority of fishes produce thrust using lateral movements of their body and caudal fin, but many other species move mainly using their median and paired fins.

4.8 TERMINAL QUESTIONS AND ANSWERS

1. This is a characteristic feature of fishes

(a) Gills and epidermal scales

(b) Tail and epidermal scales

(c) Gills and venous heart

(d) Venous heart and tail

2. Which body part of fishes helps them to change directions and keep their body balance in water?

(a) Fins and scale

(b) Fins and tails

(c) Tails and scale

(d) Gills and fins

3. Fishes move about in the water with the help of their

(a) Mouths and gills

(b) Legs and scale

(c) Wing and tails

(d) Fins and tails

4. A fish swims in water with the help of its

(a) Scales

(b) Stream lined body

(c) Fins

(d) Both b and c

Answers: 1c), 2b), 3d), 4d)

1. Write short notes on i) paired fins ii) unpaired fins

2. **Write about Anguilliform locomotion.**

3. Explain **Ostraciform locomotion**

4. Explain **locomotion in bony fishes**

LONG ANSWER QUESTION:

1. Explain the fins and locomotion in fishes.

2. Discuss the unpaired fins in fishes.

3. Discuss the locomotion process in fishes.

4.9 REFERENCES

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2. Fish and fisheries of India by Jhingran

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UNIT 5 DIGESTIVE SYSTEM

5.1 OBJECTIVES

- Breaks down nutrients into small parts for absorption
- Mastication
- salivation
- Secrete digestive enzymes
- Maintenance of fluid and electrolyte balance
- Evacuation of waste products

5.2 INTRODUCTION

The digestive system consists of alimentary canal and its associated glands. The digestive tube also contains numerous intramural glands which provide the tube by lubricating mucus, enzymes, water, etc. The extramural glands are liver, pancreas and gall bladder (Fig. 5.1.1a, b).

The liver is present in all fishes. The pancreas which is exocrine and endocrine organ may be a discrete organ or it may be diffused in the liver or in the alimentary canal. In sharks and rays (Elasmobranchii) pancreas is relatively compact and usually well developed as a separate organ, often two lobed, but in teleosts, the pancreas is diffused in the liver to form hepatopancreas.

It is also diffused in the alimentary canal in a few fishes. It is also present in the mesenteric membranes surrounding the intestine and liver. The gall bladder is vestigeal in deep sea fishes but it is prominent in other fishes.

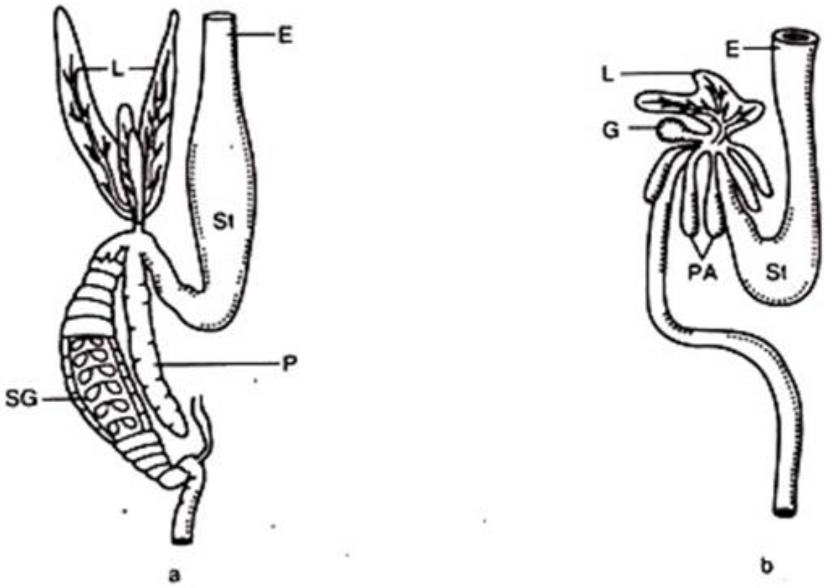


Fig .5.1.1 a,b:Diagram of alimentary canal of (a)Elasmobranch, (b) Teleost. E, oesophagus; G, gallbladder, L, liver; P, pancrease; PA, pyloric appendices; SG, spiral gut; St, stomach

While passing through the alimentary canal, the food is broken down physically and chemically and ultimately solubilized so that degraded products can be absorbed. The absorption occurs chiefly through the wall of intestine.

The undigested food and other substances within the alimentary canal such as mucus, bacteria, desquamated cells and bile pigments and detritus are excreted as faeces. The peristaltic movement and local contractions are important and help the food to pass through the gut. The local contraction displaces intestinal contents proximally and distally.

- **Parts of Alimentary Canal:**

The alimentary canal of fish consists of mouth, which opens into buccopharynx, which in its turn opens into the oesophagus. The oesophagus opens into the stomach/intestine. The lips, buccal cavity and pharynx are considered as non-tubular part whereas the oesophagus stomach/intestinal bulb, intestine and rectum are tubular in nature and distinguished as tubular part of the alimentary canal.

- **Mechanism of Feeding:**

In most teleost, the food reaches the mouth by sucking it by enlarging their buccal and opercular cavities. The pressure in the buccal and opercular cavities and pressure of water around the fish, are important for sucking. The pressure of – 50 to -105 cm of water was recorded, as food was sucked in, and + 1 to + 9 cm of water taken in with the food was driven out through operculum.

- **Stimuli for Feeding:**

The mechanism of feeding behaviour in fishes is very complicated. There are generally several kinds of stimuli for feeding. The common factors affecting the internal motivation or drive for feeding include season, time of the day, light intensity, time and nature of last feeding, temperature and any internal rhythm.

The visual, chemical, taste and lateral line system also control the momentary feeding act. The interaction of these groups of factors determines when and how a fish will feed and what it will feed upon.

The role of visual and olfactory factors in connection with feeding behaviour has been studied by experimental conditions by Groot (1971). He found visual, chemical and mechanical sense organs in Pleuronectidae, Soleidae, and Bothidae (belongs to the family of flat fishes, Pleuronectiformes).

Soleidae are polychaet mollusc feeder, feed during night, find their food mainly by olfactory clues, but still have the capability of finding their food visually, (Table1). The barbels help the fish to locate food grubbed from soft bottom material.

Table 1: Role of visual and olfactory factors in feeding

Family	Type	Way of finding food	Form of intestine	Form of gill raker	Olfactory Lobe (After Evans, 1937)	Optic Lobes (After Evans, 1937)
Bothidae	fish-feeder	vision loop	simple toothed	heavily	small	large
Pleuro-nectidae	Crustacea-feeder	Mainly vision but also olfaction	complica-ted loop	less toothed	medium	large
Soleidae	Polychae-tamollus-cafeeder	Olfaction but vision possible	more complica-ted loop	few or no teeth	large	small

On the basis of feeding habits, the fishes are categorized as follows:

1. Herbivorous

2. Carnivorous

3. Omnivorous

4. Detrivorous.

The fishes can be classified as ‘Euryphagous’ consuming mixed diet ‘Stenophagous—eating limited assorted food and ‘Monophagous’—consuming only one type of food. Amongst teleosts, about 61.5% are omnivorous, 12.5% are carnivorous and about 26% are herbivorous (fig. 5.2).

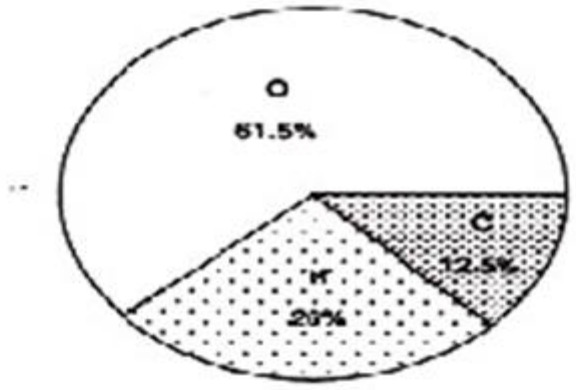


Fig 5.2.1: Diagram showing distribution of species with different feeding habits. C, carnivorus; H, herbivorus; O, omnivorous

1. Herbivorous Fishes:

They consume about 70% unicellular algae, filamentous algae and aquatic plants. In addition to plant material these fishes also consume 1-10% of animal food and mud. Herbivorous fishes have long and coiled intestine (Fig. 5.2B).This type of fish survives, grows and reproduction by eating unicellular algae, filamentous algae, small water plants, portion of higher aquatic plants, detritus along with some mud or sand. In this case, the plant materials in their food consist of about 75% or more of the total gut contents while the animal-based food varies 1-10% in its diet. For example, *Labeo rohita*, *Catla catla*, *Labeo bata*, *Ctenopharyngodon idella*, *Amblypharyngodon mola*, *Oreochromis mossumbicus*, etc.

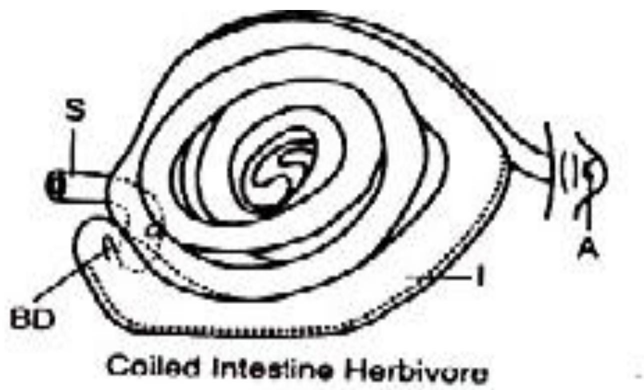


Fig 5.2.2. : Diagram of alimentary canal of a herbivorous catfish. A anus; BD, bile duct; I, intestine; S, stomach

2. Carnivorous Fishes:

The fishes in contrast to herbivore have shorter gut, the intestine is straight, very little coils are present. Some of the carnivores possess intestinal caecae. They prey on small organisms and consume high percentage of animals such as copepods, dafnia and insects.

They take large numbers of animals as food such as Copepods, Cladocerans, insects such as beetles, water bugs, damsel flies, dragon flies, larvae, Molluscs, different small fishes, tadpole larvae, etc. Some notable carnivorous fishes are *Wallago attu, Channa punctatus, channa striatus, Channa marulius, Channa gachua, Chitala chitala, Chanda nama, Chanda ranga, Rita rita, Glossogobious giuris, Mystus seenghala, Mystus cavassius, Ompok pabda,* etc. Among them some are active predators such as *Channa marulius, Channa striatus, Wallago attu, Chitala chitala, Mystus seenghala,* etc.(Fig. 5.2a, b, c, d).

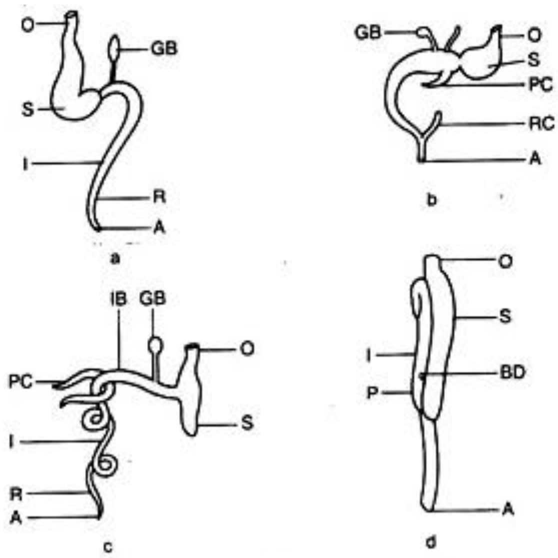


Fig. 5.2.3.a-d : Alimentary canal of Fishes. (a) Mystus seenghala; (b) Notopterus chitala; (c) Channa striatus; (d) A carnivorous fish, Esox Lucius

A, anus; BD, bile duct; GB, gall bladder; I, intestine; IB, intestinal bulb; O, oesophagus; P, pylorus; PC, pyloric caecum; R, rectum; RC, rectal caecum; S, stomach

3. Omnivorous Fishes:

Omivorous fishes like Cyprinuscarpio, Cirrhina mrigala, Puntius, Clarias, etc. are consuming both plants and animals. The rotifers, mud and sand are also found in the alimentary canal. Their gut length intermediates between carnivorous and herbivorous fishes (Fig. 5.2.4C).

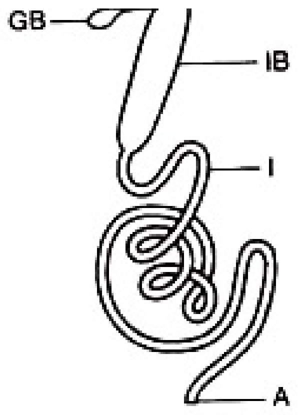


Fig. 5.2.4: Alimentary canal of Cirrhinus mrigala. A,anus; I, intestine; IB, intestine bulb; GB, gall bladder

These types of fish eat all kinds of food. Although their favorite food is insects, they also eat vegetable-based foods such as unicellular and filamentous algae, different aquatic plants when needed. Besides, they take zooplankton such as crustaceans, rotifers, insects and its larvae, mud and sands. During their young stage, most of the fish prefer to eat zooplankton. They consume varying percentage of plants and animal materials.

Among omnivorous fishes, some feed on a large amount of plant materials. Some feed on equal amount of animal and plant materials while other take a greater amount of animal foods. Some important omnivorous fishes are *Cyprinous carpio, Cirrhinus cirhosus, Tor tor, Puntius ticto, Puntius sophore, Puntius sarana, adusia chapra, Colisa fasciatus, Eutropicthyes vacha,* etc.

4. Detrivorous or Plankton Feeder:

They consume detritus along with zooplanktons and phytoplankton's. They take these types of food by filtering water using their gill rackers. The arrangement of gill rakers is such that it filters them from water. The examples are Catla catla, Hilsa ilisa, Cirrhina reba, and Hypopthalmichthys molitrix. They are both omnivorous and carnivorous.

Gizzard shad (*Dorosoma cepedianum*) fry feed on zooplankton until reach the length of one inch. They become a filter feeder after losing their teeth and consume phytoplankton and some tiny invertebrates.

Menhaden (*Brevoortia*) is also filter feeder that prefers to feed mainly on phytoplankton. They capture phytoplankton from the water using their gill rakers. Adult menhaden can filter 4 gallons of water per minute and receive different phytoplankton and zooplankton within their gills.

A silver carp (*Hypophthalmichthys molitrix*) is also a filter feeder that has a special filtration capacity. They can filter though their gills and consume lots of phytoplankton and zooplankton.

The fishes can also be named on the basis of modification of buccopharynx:

(1) Predator,

(2) Grazers,

(3) Strainers,

(4) Suckers,

(5) Parasitic.

1. Predators:

They possess well developed grasping and holding teeth, e.g. sharks, pike and gars, etc.

2. Grazers:

They take the food by bite. These fishes feed on plankton and on bottom organisms, e.g., bluegill (Lepomis macrochirus), parrot fish and butterfly fish.

3. Strainers:

They have efficient straining or filtering adaptation due to the arrangement of gill rakers forming sieve for straining the food material. They are plankton feeders.

4. Suckers:

The fishes have inferior mouth and sucking lips. The response depends upon stimulus of touch e.g., sturgeons, Labeo, Osteochilus, etc.

5. Parasites:

Amongst fishes, the deep sea eel (Simenchelys parasiticus) is parasitic in nature. Lamprey and hagfish are parasitic but belongs to cyclostomata.

5.3 FOOD RESOURCE

Fish is an important cultural icon in world. Many species of fish are caught by humans and consumed as food in virtually all regions around the world. Fish is not only an important source of nutrition, the act of catching and eating fish are important cultural and family practices as well. Fish has been an important dietary source of protein and other nutrients throughout human history. Fish is filled with omega-3- fatty acids and vitamins such as D and B2.

Fish is rich in calcium, and phosphorus and a great source of minerals such as iron, zinc, iodine, magnesium and potassium.

Eating oily fish containing long-chain omega-3 fatty acids may reduce systemic inflammation and lower the risk of cardiovascular disease.Eating about (140 grams (4.9 oz)) of oily fish rich in omega-3 fatty acids once per week is a recommended consumption amount. Increasing intake of omega-3 fatty acids may slightly reduce the risk of a fatal heart attack.

Fig. 5.3.1: fish as food

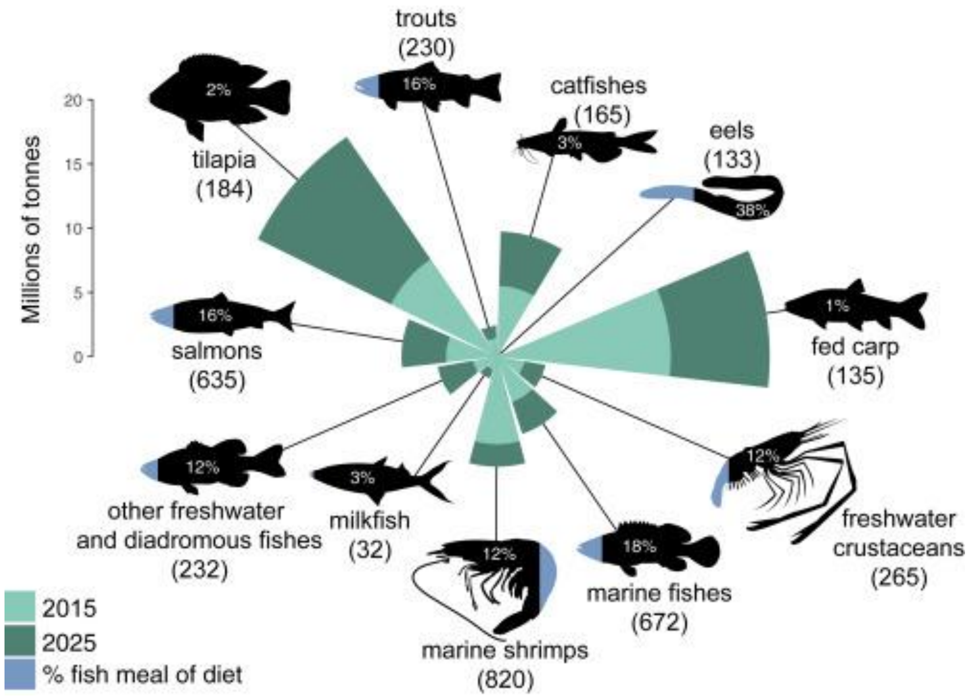


Fig. 5.3.2: Nutritive value of fish

Nutritional value

Globally, fish and fish products provide an average of only about 34 calories per capita per day. However more than as an energy source, the dietary contribution of fish is significant in terms of high-quality, easily digested animal proteins and especially in fighting micronutrient deficiencies.[1] A portion of 150g of fish provides about 50 to 60 percent of an adult's daily protein requirement. Fish proteins are essential in the diet of some densely populated countries where the total protein intake is low, and are particularly important in diets in Small Island developing States (SIDS).

Intermediate Technology Publications wrote in 1992 that "Fish provides a good source of high quality protein and contains many vitamins and minerals. It may be classed as either whitefish, oily fish, or shellfish. Whitefish, such as haddock and seer, contain very little fat (usually less than 1%) whereas oily fish, such as sardines, contain between 10–25%. The latter, as a result of its high fat content, contain a range of fat-soluble vitamins (A, D, E and K) and essential fatty acids, all of which are vital for the healthy functioning of the body."

Table 5.2

Comparison of nutrients in 100 g of whitefish or oily fish		
Nutrient	**Whitefish Alaska pollock**[5]	**Oily fish Atlantic herring**[6]
Energy (kcal)	111	203
Protein (g)	23	23
Fat (g)	1	12
Cholesterol (mg)	86	77
Vitamin B-12 (µg)	4	13
Phosphorus (mg)	267	303
Selenium (µg)	44	47
Omega-3 (mg)	509	2014

Halibut fillet (a whitefish) on top of a salmon fillet (an oily fish)

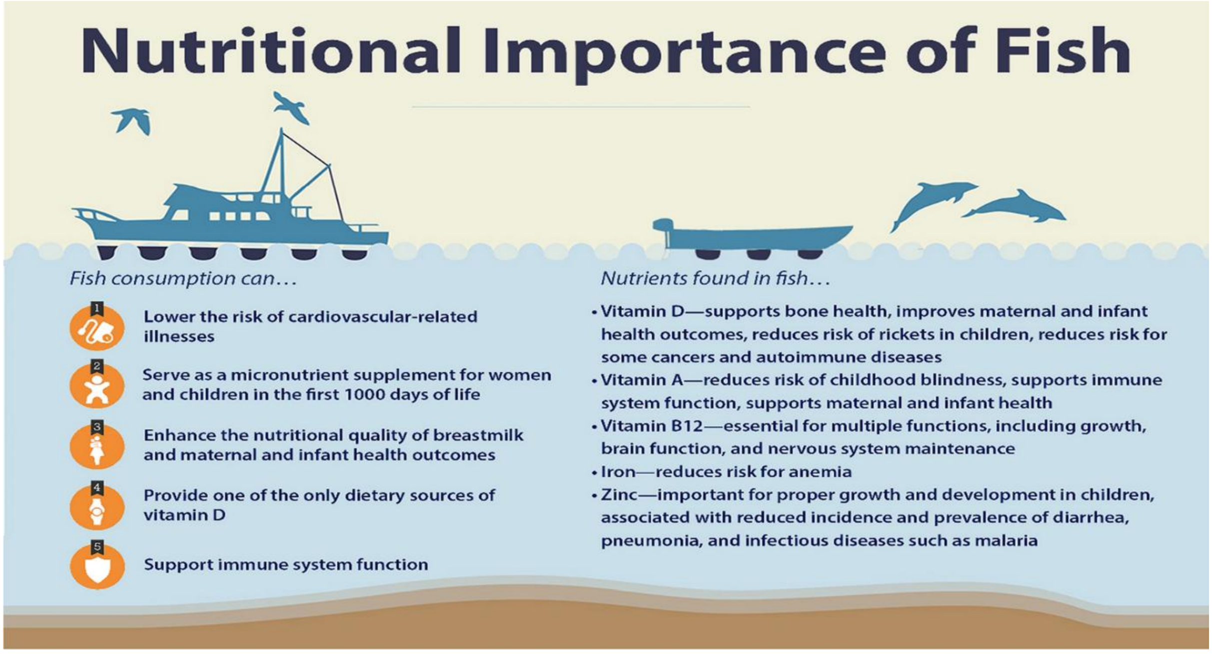
Fish as a source providing construction materials for RNA, DNA, numerous other biomolecules, cells, muscle tissues, bones, and organs that perform numerous different structural and functional roles with prevention and reduction of diseases is a super food on this planet. It is an excellent food providing all the essential amino acids, essential n-3 fatty acids, vitamins, and minerals. Fish protein is highly digestible and of high biological value. Fish contains biomolecules that enhance performance ability physically and mentally. Fish is a good food for early development..

Fish is a food for brain and health that can also be proved from the present review. Human mind is the medium through which the civilization was developed. It is the medium through which any goal and success can be achieved. Human brain can be compared to hardware in a computer while mind is compared to software. Healthy long life, enhanced physical and mental performance ability, well-being are all factors for quality life. So, it is rightly concluded that "fish is an important functional food for quality life" considering the principle of definition of functional food and its validity.

In addition to fish being highly delicious and tasty to sensory organ, the present facts and ideas will motivate more humans to choose fish as one of best functional foods for efficient and quality life.

There are variations in quality of fishes depending on species, habitat, temperature, season, feeding, etc. Special care for safety aspects should be taken in processing, harvesting, and storing effects and about fishes from toxic polluted areas.

Fish can play a crucial role in achieving global food and nutrition security.
Fish is an animal-source food (ASF), rich in micronutrients, essential fatty acids, and animal protein, which can help support cognitive development, alleviate stunting, improve maternal and childhood health outcomes, strengthen the immune system, and reduce cardiovascular disease . Fish provide 17% of animal protein and 7% of total protein consumed globally (FAO 2020). ASF (including fish) consumption is associated with reduced childhood stunting due to higher concentrations and bioavailability of key micronutrients compared to plant-source foods. Additionally, fish high in essential fatty acids can reduce risks for cardiovascular disease, with 1.4 million cardiovascular-related deaths worldwide in 2010 attributable to diets low in fish-source omega-3 fatty acids. Thus, fish nutrients can alleviate conditions related to undernutrition as well as non-communicable disease risk.



5.3.3. NUTRITIONAL VALUE OF FISH

In many contexts, fish is more affordable than other ASFs such as red meat, making it more accessible to the poor, although prices for some species are driven up by global demand. Nine countries—all from the Global South—obtain at least half of their animal protein from fish. As a wild food, fish is often available to landless people who cannot produce crops and serves as a safety net for people during economic and climate-driven shocks and geopolitical conflicts affecting land-based food production. In some regions, aquaculture prices have fallen over time, demonstrating that farming fish has the potential to serve as a pro-poor food production system. Besides being affordable and accessible, fish production systems often provide crucial nutrients with less detrimental environmental impact than other ASFs.

5.3.1 SUPPLEMENTARY FOOD AND ARTIFICIAL FOOD

When we cultivate fish in large quantities and raise them, then it will not depend only on natural food. They have to provide supplementary or artificial foods made from outside. Besides, if we depend only on natural foods, they can disrupt the entire nutrition of fish.

For more production of fish some extra feed is needed in accordance with natural feeds in water. This extra served feed is called supplementary fish feed.

In addition, organic and inorganic fertilizers are also needed in connection with a fish meal in the water body to produce the right amount of natural food. In this case, we can provide organic fertilizers such as cow dung, compost, earthworm, various types of sugarcane products and inorganic fertilizers like ammonium sulfate, urea, single super phosphate(SSP), murate of potash(MP) and so on which influence the growth of natural foods such as plankton (phytoplankton and zooplankton).

We can also provide lime regularly into the water body that enhances the health of fish, purity of water and ability to make fish food. Besides these, about ten types of amino-acids are needed in the nutrition for cultivated fish. These amino acids are called essential amino acids. These include:

1. Arginine,
2. Histidine,
3. Isoleucine,
4. Lucine,
5. Lysine,
6. Methionine,
7. Tryptophan,
8. Phenylalanine,
9. Threonine and
10. Valine.

In the supplementary diet, the required amino-acids should be at the appropriate levels. Fish food should contain 35% of protein levels. Carbohydrates are also very important nutrient components for fish. This carbohydrate generates the energy of the fish body.

Fish can store additional carbohydrates in the liver in the form of glycogen or stored in the body's muscle and when needed, they can use it. About 4 kilocalories of energy are found in almost every gram of carbohydrates.

The supplementary diet of fish should contain 1o.5 percent carbohydrates. In addition to carbohydrates, fish need to be fat for nutrition. Food should contain 4-8 percent fat. Essential fats like tocopherol should be present in the diet of fish.

Besides, protein, carbohydrates and fats, the body of the fish requires various nutrients such as minerals like calcium(Ca), phosphorus(P), potassium(K), chloride(Cl), magnesium(Mg), zinc(Zn), copper(Cu), iodine(I), iron(Fe), etc.

To make a balanced diet vitamin should be added to the supplementary food. In this case, different types of vitamins such as Vitamin A, Vitamin B (riboflavin, pyridoxine, niacin), Vitamin E Vitamin D and Vitamin K are the most important.

Supplemental food of fish is also made using animal-based ingredients such as fish powder, silkworm pupa, animal, slaughterhouse meat and blood, etc. Plant-based ingredients such as mustard oil cake, coconut cake, soybean meal, rice bran, wheat flour, wheat bran, etc are also used to make fish food.

Introduction of some supplementary fish feed are described below.

Rice Bran: Rice dust is like powder. It is very common and cheap. It is a better fish feed. Rice dust contain about 10–14% of protein. Rice dust also contains vitamin B1, B2, B6 and small quantity of enzyme.

Mustard Cake: Mustard cake can be found in small sized pieces. It is slightly yellow colored. Mustard cake has to served to fish by mixing with other food. Fat may gather in the liver of fish for long time consuming of cake. As a result the fish may die. Mix maximum 40% of cake in the fish feed. But don’t use dry cake more than 20%. Mustard cake contain 30–32% protein. It also contain a high rate of fat.

Wheat Chaff: Wheat chaff contain fiber. It controls many types of fish diseases. Amount of fat in wheat chaff is low. So, it is better than rice dust as feed. Amount of protein in the wheat chaff is 10–15%.

Maize: Maize is yellow colored grainy feed. It is the best among the vegetate supplementary feed. Generative fish gain maturity vary fast by feeding maize. Maize contain protein, carbohydrate, fat, vitamin A and E.

Cotton Seeds: It contain about 54% protein. It is a better ingredients for supplementary fish feed.

Tiny Moss: There are various types of moss available. They are of green colored. They are floaty water plants. This types of moss contain about 14–20% protein.

Fish Powder: Fish powder or fishmeal are brown colored. It is easily digestible to fish. Fishmeal contain about 55–60% protein.

Bone Powder: The color of bone powder is dim white. It is very necessary for building fish-bone. The ratio of calcium and magnesium in the bone dust is 2 : 1.

Animal Blood: The dry animal blood is coppery colored. It can be found in the slaughter house. Blood is used as fish feed by mixing with other feed. It is an ideal feed ingredients for catfish. Liquid blood contain 63% and dry blood contain 82% protein. Two necessary amino acids are available in the blood of animal.

Innards of Animal: Innards of animal is a very suitable and ideal feed for catfish. It contain 52% protein.

Vitamin: Vitamin is a necessary ingredients of fish feed. It keeps the fish healthy and disease free.

Others: Along with the above mentioned feed ingredients, the fish also need some more elements in their feed. Vitamin premix, salt etc also helpful for fish.

Except those supplementary feed, it is very necessary to provide extruded fish feed (produced by fish feed extruder) along with natural feed for better production of fish.

- **Features of Supplementary Food**

The availability and low cost of plant-based foods such as rice grain, rice bran, etc are usually used to make supplementary food in combination with mustard oil cake, or groundnut cake. They also reduce the cost of production. The price of coconut cake is relatively high, so the use of mustard oil cake is more prevalent.

- **Artificial Food:**

Artificial fish food is a type of substance that helps fish or shrimp growth, regulate health, produce heat and energy, and reproduce after being fed as a natural food supplement. In modern aquaculture, fish feed is an integral part of a source of nutrients and energy for the growth, reproduction and health of fish.

- **Artificial Fish Feed Types**

Artificial fish food is usually prepared as floating or buoyant or sinking food. Both types of food help in the satisfactory growth of fish but some fish species prefer floating food while some species prefer drowning food. Shrimp do not eat floating food but most fish species are quite adept at eating floating pellets. It is quite expensive as the production cost of floating food is high. One of the advantages of this type of food is that the fish farmer can easily observe the food intake of fish directly and can also determine the rate of food accordingly. It is very important to determine whether the rate of food intake is too high or too low for maximum growth of fish and food utilization efficiency.

Variations in the size of the fish diet are observed. In particular, it ranges from a fine piece to a large pellet. The size of the pellet is usually 20-30% of the mouth of the fish species. In order to eat small size pellets, the fish has to find a large number of pellets, which consumes a lot of time and energy. So the pellets are usually of medium size.

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Different types of artificial food are used in intensive and semi-intensive fish farming. Two types of artificial foods are commonly used, viz

1. **Dry Feeds**
2. **Non-dry feeds**

1. Dry Feeds

This type of food is made with dry food ingredients or a mixture of dry or moist ingredients. Usually this type of food is not completely moisture free, it usually contains 8-10% water and it depends on the environmental conditions. This type of food is usually free of bacterial infections. Such food is divided into two types, viz

(A) Mashes or Meals: Foods that are made with very common dry food ingredients are called Mashes or meals.

(B) Pellets: Foods that are dry and have a certain size are called pellets.

2. Non-dry Feeds

There are usually two types of non-dry feeds, such as wet or moist. Usually wet food is made up of different types of wet ingredients such as fresh or frozen, whole, shredded or abandoned fish, other wastes including cattle slaughter blood and non-dry vegetable ingredients etc. The fish used to make wet food are herring, caplin, mackerel, blue whiting and sand lance. This type of food is more or less made from squid or other marine animals. This type of food contains 45-70% moisture. The use of such foods has declined to a large extent due to the increase in the production and use of formulated foods. Wet food is mainly used for certain marine species. The harmful side of such food is that it contaminates the water. As a result of consuming such food, many disease germs are transmitted through it. Due to the variation in the size of such food, more food is wasted which contributes to water pollution, so the use of such food is regulated in different countries, especially on freshwater farms.

Moist food is made with a mixture of dry and wet ingredients or when it is made with dry ingredients it is mixed with water. All these foods contain 18-40% moisture. Some species of fish prefer moist foods to dry foods. This type of food is widely used in salmon hatcheries.

Non-dry foods, especially moist and wet, tend to be pellet, ball or cake shaped. Both types offood are made with a combination of vitamins, minerals, oils and additives.

- **Artificial Feed Selection Criteria for Fish**

- Ingredients for artificial foods should be cheap and locally available.
- Palatable feed ingredients should be selected so that fish can be easily accepted due to its palatability.
- You should use such types of ingredients that help to increase the fish yield so that you can earn extra money by selling your fish.

Fig.5.3.4: Natural fish food

- **Natural Fish Food**

Natural food is found naturally in the pond. It may include **detritus, bacteria, plankton,worms, insects, snails, aquatic plants and fish**. Their abundance greatly depends on water quality. Different types of food are produced naturally in ponds or reservoirs. These are called natural foods. They are very small and their movements depend on the direction of the water current that helps goes towards them. They are known as plankton. Plankton can be seen in all types of reservoirs, except for high flowing rivers.

Plankton is one of the small flora and fauna whose movement capacity is so limited that they cannot cross the stream. Therefore, in most aquatic environments, movements of a large number of plankton species are controlled by wave and water currents.

Table 5.4: Average composition (in percentage by weight) of some of the supplementary feedstuffs used in aquaculture.

	Dry matter	Crude protein	Crude fat	Carbohydrate (nitrogen-free extract)	Crude fibre	Ash	True protein
Fresh plant material							
Ipomoea reptans	7.5	2.1	0.2	2.9	0.9	1.4	—
Sweet potato leaves and stem (*Ipomoea batata*) (Congo)	13.0	1.6	0.4	6.8	2.3	1.6	
(*Ipomoea batata*) vine (China)	12.4	2.08	0.67	5.96	2.43	1.26	
Tapioca leaves (Congo) (*Manihot utilissima*)	27.3	8.8	0.9	6.2	9.8	1.7	
Guinea grass	23.0	2.9	0.2	10.3	6.6	3.0	
Cynodon datylon (land grass)	22.4	4.89	0.78	10.40	4.17	2.0	
Maize (Europe)	87.0	9.9	4.4	69.2	2.2	1.3	9.4
Oats (Europe)	87.0	10.4	4.8	58.4	10.3	3.1	9.5
Barley (Europe)	85.0	9.0	1.5	4.5	2.6	8.5	6.8
Oil cakes							
Soybean cake (China)	89.9	40.9	3.51	35.69	4.34	5.46	
Groundnut cake (China)	88.55	39.51	3.56	33.36	3.55	8.57	
Coconut cake	90.0	21.2	7.3	44.2	11.4	5.9	19.7
Palm kernel cake	89.0	13.1	10.0	54.9	7.7	3.3	
Mustard seed cake (China)	89.8	24.64	1.06	41.66	7.10	15.34	
Cotton seed cake (decorticated)	90.0	41.1	3.0	26.4	7.8	6.7	39.6
Cotton seed cake (China)	91.3	36.58	4.99	33.41	8.31	8.01	
Bran							
Rice bran (China)	89.0	13.68	17.9	37.02	6.84	13.56	
Fine rice bran (Malaysia)	89.2	11.4	6.8	45.4	14.1	11.5	
Coarse rice bran (Malaysia)	90.5	6.2	2.7	37.8	33.1	10.7	
Wheat bran (China)	87.2	11.33	2.64	58.25	8.87	5.51	
Wheat bran (Europe)	85.1	15.0	3.2	54.1	7.5	5.3	
Cotton seed bran	92.6	3.38	0.91	46.14	37.01	5.23	
Animal products							
Trash fish	28.0	14.2	1.5	—	—	10.7	
Blood meal	86.0	81.0	0.8	1.5	—	2.7	71.9
Cattle liver	25.0	21.2	0.6	—	—	1.0	
Small clams (flesh)	15.93	13.20	0.77	—	—	1.20	
Small shrimps (dry)	82.80	55.45	5.52	4.37	—	17.65	
Silkworm pupae, fresh	35.4	19.1	12.8	2.3	—	1.2	
Silkworm pupae, dried	90.0	55.9	24.5	6.6	—	1.9	
Silkworm pupae, dried and defatted	91.1	75.4	1.8	8.4	—	5.6	
Miscellaneous							
Soybean curd residue	10.75	2.38	0.41	5.39	2.19	0.38	
Brewers grain (dried)	89.7	18.3	6.4	45.9	15.2	3.9	17.4

Most plankton (phytoplankton and zooplankton) can control vertical expansion through a slight movement. Some animal plankton or zooplankton can be more active and move more distances than their microbial bodies. However, their size is so small that their movement is greatly controlled through the water current or wave. This type of plankton is called nektoplankton.

Plankton are of two the following types:

1. Phytoplankton
2. Zooplankton

1. Phytoplankton

Phytoplankton are the autotrophic organisms that play a key role as the natural food of various fish species. Most of the phytoplankton are not seen by the naked eye due to their microscopic structure. But when present in large enough, they produce colored patches on the water surface because of the presence of chlorophyll, phycobiliproteins or xanthophylls in their cells.

Phytoplankton form about one percent of the global biomass. The watercolor becomes green to yellow or green to brown due to the presence of plankton. They are the ideal food for fish.

- **Green Algae**

They are a portion of very popular fish food. Their main feature is the presence of chlorophyll or green particles in the body. Sometimes water surface is covered by a layer due to the abundance of such green algae and afterward, the water is polluted.Among the various green algae, *Chlorella*, *Chlamydomonas*, *Eudorina*, *Volvox*, *Scenedesmus*, and *Ulothrix* are notable. These kinds of algae do not live for a long time. Overall, they are regulated when fertilizer and supplementary foods are stopped.

- **Blue-Green Algae**

They are also plant-like microscopic organisms that grow in water bodies such as ponds, rivers, lakes, and streams. They are blue-green but can also be olive-green or red in color. They also play important fish food while alive and dead. Blue-green algae do not normally visible in the water, but their populations can increase rapidly to form a large mass or scum, known as bloom.

The bloom can cause harm to fish because they prevent sunlight into water bodies and make the depletion of oxygen level. The bloom commonly occurs during the summer months and when they form dense blooms then they make the water look bluish-green color.

Generally, if nutrients like phosphorus and nitrogen are available in the water that contributes to the growth of the blue-green algae. The algal bloom can also occur due to agricultural and stormwater runoff and leaching from septic systems.

- **Harmful Effects of Algal Bloom**

- If the large numbers of algae grow in the water body they consume a lot of oxygen at night and the water body becomes an oxygen-free state. As a result, fish die due to a lack of oxygen. In addition, the plants also die and fall into the water and reduce oxygen in the water.
- If the growth of algae is high, two layers are formed on the water surface. Temperature and oxygen content greatly vary in these two levels which is harmful to fish. Temperatures and oxygen levels are higher in the upper layers of the water, while the temperatures and oxygen in the lower levels are very low. In this case, the sunlight cannot reach the bottom of the water body because of the layer of algal blooms.
- The pH of water also increases abnormally during the day time due to the abundance of algae.
- Besides, different blue-green algae such as *Oscillatoria*, Microsystis, etc. release toxin in the water which inhibits the growth of different zooplankton such as *Daphnia, Cyclops, Diaptomus, Bosmina* as well as fish.
- **Preventing Measures of Algal Bloom**

The following simple steps should be taken to prevent the growth of blue-green algae:

- Using phosphate-free detergents, and household cleaning products.
- You can also prevent it by providing personal care.
- By stopping or minimizing the application of fertilizers that contain phosphorus.
- Preventing agricultural runoff by making plantation along the waterways.
- Making reconstruction of natural shoreline on the lake and other water bodies.
- By confirming or checking the septic system that does not leak into the water source.

2. Zooplankton

Plankton play an crucial role in aquaculure. All kinds of animal plankton are known as ‘zooplankton’. Zooplankton are one kind of heterotrophic organisms. They mainly feed on phytoplankton but some are detritivorous. Their body size range from microscopic to large-sized such as jellyfish which are visible in the naked eye.

They inhabit different types of water bodies such as the freshwater system and oceans. Zooplankton are the ecologically important organisms that maintain the essential constituent of the food chain.

They are larger than phytoplankton. When many numbers of zooplankton are raised in the water bodies, the watercolor is gray or light brown or light black.

They are the main food of fish larvae and fingerlings. Among zooplankton, some types of lower animals are available in the reservoir, known as rotifers. These are the favorite fish food.

5.4 FEEDING HABITS IN FISH

The inland water bodies consist of small aquariums to nursery ponds, canals, beels, haor, baors (oxbow-lake), rivers, streams, flooded lands, etc. These are called freshwater basins. The more diverse fish types are found in these water bodies. The shape, nature, feeding habits, color, etc. vary from species to species. Their cultivation system is also different. It is important to have scientific knowledge about the nature of fish, feeding habits, diseases and so on to cultivate fish through the choice using suitable control measures. Food and feeding habits of fish is very important factor that helps to choose the fish type for cultivation.

Fish can also be classified into the following three types based on the niche they occupy in different water levels.

- **Surface Feeders**

The uppermost layer of water, where sunlight enters, grows a large number of plankton which produce their food through the process of photosynthesis using their chlorophyll. At this level oxygen is even higher which is suitable for various animal organisms. *Catla catla* is mainly stay at this level to collect food. Silver Carp is also a resident of this level. Besides, *Puntius ticto, Oygaster bacaila, Chanda ranga, Chanda nama, Glossogobious giuris,Tenualosa ilisha, Gadusia chapra,* etc are notable surface feeder fishes.

- **Column Feeders**

Some species of fishes take their food from the mid water. At this level water waves are relatively few but zooplankton, phytoplankton are available with sufficient amount of oxygen, suitable for fish. The fish that live here are neither true bottom nor true surface feeders. They mostly depend on the food of the middle layer of the water. *Labeo rohita*, *Labeo bata, Tor tor, Puntius sophore*, *Mystus seenghala*, *Wallago attu*, *Mystus vittatus*, etc are the column feeder fishes.

- **Bottom Feeders**The bottom feeder fish mainly depend on food for bottom organisms. At this level, lots of benthos live here that provides nutrients to the fishes. *Labeo calbasu*, *Labeo gonius, Cirrhinus cirrhosus, Puntius sarana,Amblypharyngodon mola,*

Scientific Name of Fish	**Order Name**	**Feeding Habits**	**Food Types**
Mystus seenghala, Wallago attu,	Siluriformes	Carnivorous and Predatory	Fish fry, insects and its larvae, fingerlings, small fishes, tadpoles, frogs, etc.
Channa marulius, Channa striatus, Chitala chitala	Cahnniformes	Carnivorous and Predatory	Fish fry, insects and its larvae, fingerlings, small fishes, tadpoles, frogs, etc.

Clarias batrachus	Siluriformes	Omnivorous	Insects, worms, crustaceans, fish fry, insects larvae, decaying organic maters, etc.
Heteropneustes fossilis	Siluriformes	Omnivorous	Insects, worms, copepods, ostracods, debris, algae, etc
Labeo rohita	Cypriniformes	Herbivorous	Algae, microscopic plants, vegetable matters, detritus, sand and mud, etc.
Osphronemus goramy	Anabantiformes	Herbivorous	They mainly feed on aquatic plants and algae.
Oreochromis mossambicus	Cichliformes	Herbivorous	They mainly feed on aquatic plants and filamentous algae.
Ctenopharyngodon idella	Cypriniformes	Herbivorous	They voraciously feed on aquatic vegetation.

Hypopthalmicthys molitrix	Cypriniformes	Plankton feeder	Unicellular algae, rotifers, decaying microorganisms, detritus, etc.
Catla catla	Cypriniformes	Plankton feeder	Microscopic plants, Algae, rotifers, insects, crustaceans, etc.
Cirrhinus cirrhosus	Cypriniformes	Omnivorous	Algae, decaying plants, and animal matters, detritus and mud, etc.
Tor putitora	Cypriniformes	Omnivorous	Algae, decaying organic matter, insects, rotivers, protozoans, etc.
Tor tor	Cypriniformes	Omnivorous	Macro vegetation, filamentous algae, mollusks, sands and muds, etc.
Cyprinus carpio	Cypriniformes	Omnivorous	Algae, macro-vegetation, insects, rotifers, crustaceans

Cirrhinus reba, Clarias batrachus, Heteropneustes fossilis, Channa striatuis, Channa marulius, etc are notable bottom feeder fishes.

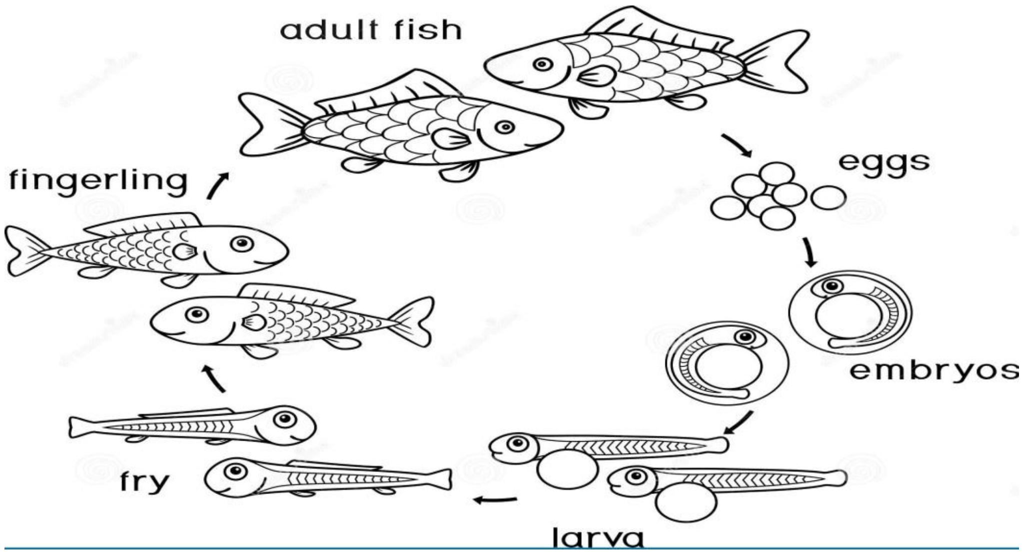


fig.5.4.1: Different life stages of fish

FEEDS BASED ON LIFE-CYCLE OF FISH

Feeds can be classified based on the stage of the life cycle at which they are targeted.

- **Starter feeds**

Starter feeds are given as first feeds to feed the fry or larvae, when their yolk is exhausted or about to be exhausted. The transformation from an endogenous to an exogenous food supply is critical and thus starter feeds should be nutritionally complete, easily digestible, and with appropriate particle size. Starter feeds are generally in the form of fine crumbles or flakes. However, in the case of shrimps starter feeds are given to post larvae up to 0.5 g size juveniles.

- **Fry feeds**

Fry is the term used for the unmetamorphosed young stage in the life cycle of fish. Fry feeds generally contain higher levels of protein because the protein and energy requirements are high in the early stages of life because the highest relative weight gain is achieved in the fry stages. Fry feeds are generally in the form of flakes or crumbles.

- **Fingerling feeds**

The fingerling stage is defined as metamorphosed younger stage of fish to a growth of about 10-20g. Fingerling feeds vary from crumbles to pellets depending on the species to be cultured and their size. Fingerling diets tend to contain less protein and energy than fry and starter diets.

- **Grow-out feeds**

The weight increase in fish during this grow-out stage is at a uniform rate, decreasing slightly as the fish increases in weight. Thus the nutritional requirement during this stage is rather uniform. It is important to ensure that the protein that the protein in the feed is used mainly for growth and not for metabolic activity. The biomass increments are considerable and also the quantity of feed administered is high. Thus, during this stage cost-saving feeds are essential. Generally pellet form of the feed is employed during grow-out stages.

- **Broodstock feeds**

Adequate nutrition has an important role to play in the reproductive success of fishes. A number of aspects of reproduction like the time of first maturity, number of eggs produced (fecundity). egg size and egg quality as measured by chemical composition, hatchability and larval survival can be affected by nutritional status.

It has been shown that essential fatty acids, vitamins (A, E and C), trace minerals and carotenoids can affect fecundity, egg quality, hatchability and larval quality. Nutritional requirements of broodstock can further differ depending upon the phase of reproductive period. Formulation of complete diets should, therefore, take into account the stage-specific, as well as species-specific nutritional requirements of the broodstock. Nutritionists and the feed industry should also consider the options for developing three types of broodstock diets:

- conditioning diet
- reproduction diet
- recovery/maintenance diet

The broodstock conditioning diet should be formulated as an optimized growout diet to meet the full nutritional requirements of the species from commercial to broodstock size. The reproduction diet used before or during spawning should meet the needs for maximal reproductive performance (spawning success and fecundity), gamete quality, and transfer of nutrients and biologically active substances to offspring. The recovery/maintenance diet should assist recovery from reproductive exhaustion and reconditioning for the next reproductive cycle.

Protein requirement in freshwater

Life stage	Weight (g)	Requirement (%)
First feeding larvae		45-50
Fry	0.02-1.0	40
Fingerlings	1.0-10.0	35-40
Juveniles	10.0-25.0	30-35
Adults	25-200	30-32
	>200	28-30
Broodstock		40-45

Table.5.6:Protein requirement in different stages

5.5 FEEDING BEHAVIOUR AND ADAPTATION OF FEEDING

Feeding behavior is a complex behavior that is closely associated with food intake. Fish have a wide variety of feeding habits and feeding patterns making them good experimental models for the study of the regulation of feeding behavior. The aquatic nature of fish often creates challenges in the study of feeding behavior and different approaches have been used by researchers, including field studies, observations of free-living animals, and laboratory experiments. Feeding behavior is regulated by a number of environmental factors and also by complex homeostatic mechanisms that involve central and peripheral hormonal factors as well as metabolites.

Feed is one of the most important external signals in fish that stimulates its feeding behavior and growth. The intake of feed is the main factor determining efficiency and cost, maximizing production efficiency in a fish farming firm. The physiological mechanism regulating food intake lies between an intricate connection linking central and peripheral signals that are unified in the hypothalamus consequently responding to the release of appetite-regulating genes that eventually induce or hinder appetite, such as apelin; a recently discovered peptide produced by several tissues with diverse physiological actions mediated by its receptor, such as feed regulation. Extrinsic factors have a great influence on food intake and feeding behavior in fish. Under these factors, feeding in fish is decontrolled and the appetite indicators in the brain do not function appropriately thus, in controlling conditions which result in the fluctuations in the expression of these appetite-relating genes, which in turn decrease food consumption.

The result of food intake is the alteration that lies between starvation, craving, and satiation. Starvation is the physiological necessity for food, including a strong incitement to feeding behavior; looking for food and consuming it. Satiation is the physiological and rational sense of “fullness” that happens after food intake whiles appetite or craving, on the other hand, is the desire to eat, which is commonly related to the material (find, fragrance, taste) perceptiveness of the food to be consumed.

Feed is among the most authoritative signals outside the fish’s body that can arouse feeding behavior and growth. Its readiness and composition exert a key control of these processes, by acting principally on the hormones responsible for their endocrine control. Some central and peripheral appetite regulators in fishes are affected by a single meal, showing per-prandial fluctuations in their expression and/or secretion levels. Such changes in fishes have been identified in the brain hormone. The search for food and its intake in fish is girded by a series of behavioral acts matched through a supportive work between the nervous and endocrine systems. The control of feed ingestion behavior is a remarkable multifaceted development that comprises particularized interactions between the brain and marginal indications. The metabolic sensors located in the central nervous system of fishes provide room for the hypothalamic systems to receive nutritional information, allowing a qualitative control of food ingestion. The neural effectors of the hypothalamic origin facilitate the control of food consumed by the fish, thus, by integrating between hunger and satiety signals which include apelin and neuropeptide Y for hunger hints and amylin and cocaine-and amphetamine-regulated transcript for satiety hints. As important as it is, it interests more fisheries and aquaculture firms in curbing fish growth and reproduction by changing food and/or endocrine settings.

Fish feeding behavior is miscellaneous and has been broadly examined in both wild and farmed fish from their ecological perspectives whiles behavioral responses of fish to feeding have been associated with feeding approaches, feeding habits, feeding regularity, feed detection mechanisms and feed preferences. Feeding behavior and its regulation in fish comprises of external and internal environment information being analyzed by signaling molecules and receptors in the fish. Thus, the hypothalamus, assisted by other brain sections in the fish, integrates inbound indications. As ascertained by Volkoff and colleagues, changes in dietary behavior and cravings are frequently related to changes in gene expression and/or protein content of the appetite regulators or their receptors. That is to say, changes in the mRNA/protein levels of a given hormone due to starvation or feeding have the probability of reflecting its physiological role in regulating feed ingestion.

EXTRINSIC FACTORS INFLUENCING FEEDING AND FEEDING BEHAVIOR IN FISH

Generally, hunger stimulates the behavioral response of feeding fish. When feed is available, fish may initially feed at a faster rate and slowly decrease or stop with a gradual decline of appetite. Feeding behavior despite being influenced by intrinsic factors is extremely influenced by ecological or extrinsic factors. Below, we highlight some of these environmental factors that influence food ingestion and feeding behaviors in fish.

- **Stress**

Stress has been defined as the disturbance of physiological or biological mechanisms due to internal and external factors, which are generally designated as stressors . These provoke a cataract of consistent behavioral and biological rejoinders in which a living organism makes efforts to reestablish homeostasis, consequently incapacitating the threat. In an aquaculture firm, cultured fish are restricted, captured, crowded, sedated, held, and transported during repetitive husbandry . In consequence, all these taken into consideration are ordinary events in fish farming and they are possible stressors that interrupt the behavioral and biological mechanisms of the organism. Thus, causing a functional response crucial to recover the dynamic consistency . Reduction in feed ingestion has been described to be distinctive behavioral feedback to stress in fish . Undeniably, stress can also disrupt several feeding conducts in fish, including the food search, finding, or capturing prey leading to a decline in growth in several fish species . Fish under stressful conditions as compared to unstressed fish eat less and have slow growth. Even when food intake levels are maintained in fish, these conditions are known to persuade a decline in the conversion efficiency of feed consumed, leading to the decreased growth rate . For example; a research by Lee and colleagues revealed that acute physical stress caused by cleaning once or thrice a week reduced the daily and cumulative feeding levels and feed conversion efficiency significantly in the sea bass (*Dicentrarchus labrax*). Furthermore, these stressors have been known to adjust the control of endocrinal growth alliance in fish such as the secretion of pituitary growth hormone, among others. In the two subsections below, we discussed two key stressors that influence the well-being of fish, which needs keen attention.

- **Temperature**

There have been several demonstrations of the relationship that exists between temperature and feeding in several fish species. Temperature is one of the most dominant factors influencing some key biological functions in fish, including feed ingestion and feeding behavior. Relatively, despite the complex and species-specific effects of temperature in fish, the relation between feeding/feeding behavior and temperature is like a bell-shaped structure at normal temperature conditions, the voluntariness of food intake also increases and/or is maintained during the acclimatization period of temperature which is specific to a particular species. On the other hand, when there's a slight decrease in temperature, the fish adapts to the temperature and maintains its feeding rate for a short period. It has also been ascertained that before the ultimate maximal/minimal critical temperature for a species reaches, it will lose appetite, cease, and lastly stop feeding. Examples given here revealed that, a research conducted on Atlantic cod (*Gadus morhua*) revealed that, when kept in a water temperature of 2°C for four weeks, there was a decrease in feed consumption compared to those kept in 11°C and 15°C water temperature. Also, research conducted on the red-spotted grouper (*Epinephelus akaara*) revealed that when the water temperature is around 25°C, there's an increase in its feeding and digestion level. However, it should be taken into consideration that when the optimal temperature of a particular fish species reaches and/or exceeds, it results in a gradual decline in feeding behaviour.

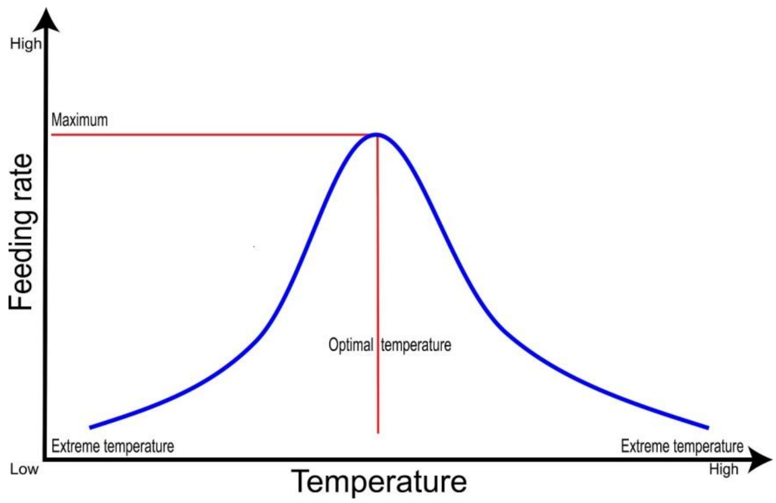


FIGURE 5.5.1: general relative relation between feeding rate and temperature of fish species. The feeding rate decrease and subsequently stops at higher or lower temperatures (extreme temperatures).

- **Hypoxia**

Dissolved oxygen (DO) is among the most significant extrinsic factors in fish farming. It is known to be a key restrictive factor in aquaculture with the particular reason for the circumstance being that, fish have aerophilic absorption which requires DO at efficient levels. The depletion of DO concentration (hypoxia) in water bodies has been identified to be a stern extrinsic stress, which commonly occurs in high-density aquaculture. Reports have indicated that growth, survival, behavior as well as other physiological activities of some fish species are highly influenced by different degrees of hypoxia and is also known to be an endocrine disruptor .

Fish under severe hypoxia conditions experience reduced movement or feed intake to conserve energy. In research conducted on the Atlantic salmon (*Salmo salar*) with regards to the hypoxic period and its physiological activities, results revealed that there were behavioral changes associated with oxygen shortage and physiological stress in some groups. Also, the severity of hypoxia reduced the intake of feed in the fish. In a research study on tilapia (*Oreochromis niloticus*) it was discovered that fish kept in hypoxic conditions had significantly reduced feed intake, survival rate, and weight gain. Additionally, a research study on rainbow trout (*Oncorhynchus mykiss*) demonstrated that hypoxia reduces feed consumption, growth rate, oxygen consumption, energy, and lipid contents. On the other hand, research conducted on tilapia (*Oreochromis niloticus*) comparing three DO (normal, low and medium) levels showed that, the final fish weight of those in the normal DO levels group were significantly higher as compared to those in the low and medium DO levels groups. Additionally, fish under the low DO level group demonstrated a lower feed intake rate. The low DO level group also revealed that fish in this group had a lower growth and feed utilization rate. This significantly demonstrates that when fed under enough DO levels, fish show good efficiency of their feed intake , which will most importanlt aid in good feed conversion ratio, fish growth and reproduction in the absence of any other stress. Hypoxia has been discovered to persuade primary, secondary, and tertiary stress responses in fish. However, most fishes can adapt to the variations in DO levels but if severe hypoxia remains, fish will sooner or later die.

Cultured fish always face repetitive and chronic hypoxia stress especially from overcrowding which they can barely escape due to their confined environment. Therefore, it is suggested that DO levels should be checked and highly maintained near the saturation level. In doing so, it enhances feed intake, feeding behavior, fish growth as well as improves the overall wellbeing and performance of the fish, as the result of hypoxia on the biological or metabolic actions of farmed fish would be negatively affected. A deep look into an article by Abdel-Tawwab and colleagues gives more insight into the effects of hypoxia on fish growth and physiological activities.

- **Photoperiod and Light Regime**

Photoperiod has been known to influence and manipulate some biological functioning in fish . Research conducted on several fish species have revealed that photoperiod and the light regime influence their feeding activities. Photoperiod plays a significant part in the growth and survival of fish, thus influencing its feed intake and feeding behavior. It is known to have the ability to affect the general wellbeing and routine of fish.

The requirements of photoperiod and light concentration in fish are species-specific and differ for the several developing phases. Consequently, whiles this could be related to fish species specificity, when photoperiod is appropriately applied, it may aid in an advanced performance of the fish, thereby improving the productivity and sustainability of aquacultural practices. For example, a research study conducted on catfish (*Clarias gariepinus*) fingerlings cultured under three different photoperiod conditions; 24 hours (hrs) darkness, 24hrs light and 12/12hrs darkness and light revealed that those cultured under 24 hrs of darkness had significantly highest feed intake, best feed conversion ratio and lowest quantity of uneaten feed as compared to those cultured under 24hrs light and 12/12 hrs of darkness and light. Also, in a research study on the pacamã catfish (*Lophiosilurus alexandri*), it was revealed that 24hrs continuous light led to the highest feed intake. Going more further, in research conducted on the sharp-snout seabream (*Diplodus puntazzo*) it was concluded that although feeding behavior was strictly diurnal, 97% of feed demands were made during the light periods. A detailed look into how photoperiod affects fish species feed intake and feeding behavior will be of much importance.

- **Circannual and Circadian Rhythms**

All these external factors that impact the feeding behavior in fish have periodic or recurring styles. Thus, they affect food intake unswervingly *via* cyclical and or 24-hourly rhythms or ramblingly through rhythms in endocrine systems. All animals, even fish, showcase natural behavioral rhythms, including the two principal feed intake rhythms in fish; the daily (circadian) and seasonal (circannual) rhythms.

Several organisms including fish, exhibit annual rhythms in physiological and behavioral factors, such as feeding, reproduction, body weight, hibernation, and movement. These factors are controlled by oscillations in the secretion of hormones. The timing of these annual rhythms is delimited by changes in day length, photoperiod, or temperature, which makes available a reliable and predictive indicator of seasonal changes in environmental conditions. The circannual (seasonal) rhythms in vertebrates (fish) associate meticulously with ambient environmental factors, thus environmental (water) temperature and the length of the day. During the spring and summer seasons, when the days are longer and the temperature of water bodies is higher, several fish species increase their feed intake as well as their feeding behavior. There is limited information on how these seasonal or circannual rhythms influence feed ingestion and feeding behavior in fish, making it complex to give a straightforward conclusion about feeding activities and associated seasonal changes. As it stands now, we recommend that more research be conducted on fish feeding and feeding behavior regarding the impact of the circannual rhythms.

The circadian rhythm is a natural rhythm that is regulated by a biological daily clock that proceeds in a steady setting. This biological clock is a 24-hour cycle in the biochemical, physiological, or behavioral processes of a live organism geared for maximizing cellular activities and recognizing solar day-related environmental obstacles. The 24-hourly rotations of behavior and physiology (example; feeding activity) have been established in all classes of craniates, including some fish species. Several inward or endogenic clocks prompt these circadian cycles. They consist of an independent transcriptional-translational response grummet that encompasses the recurring circadian-regulative genes expression and perseveres under continuous extrinsic circumstances, such as photoperiod.

As in many animals, fish species consume meals at specific times during the day or night. That is to say that in fish circadian rhythms, the natural daily food ingestion times differ among species. Some classify specifically as daytime feeders such as Atlantic salmon, *Salmo salar* , redbelly tilapia (*Tilapia zillii*) rohu (*Labeo rohita*), and common carp (*Cyprinus carpio*) whiles others are described as night time feeders, example; European catfish (*Silurus glanis*) and Zebrafish (*Danio rerio*) . Additionally, several fish species have showcased ideal times of eating daily (day or night). For example, research studies conducted on goldfish (*Carassius auratus*) and rainbow trout (*Oncorhynchus mykiss*) respectively revealed that the intake of food and the composition of the body is influenced by the time a single daily meal is delivered whiles rainbow trout (*Oncorhynchus mykiss*) fed during their habitual or natural eating times have higher feed efficiency .

There are approximately a handful of known genes or hormones which regulate feed intake in fish species, including neuropeptide Y, peptide YY, ghrelin, galanin, apelin, among others. These appetite-regulating genes influence the intake of feed in two ways; feed intake inducer or inhibitor. The appetite-inducing hormones persuade or signal hunger in fish, thus causing them to search for food to eat (orexigenic factor). On the other hand, appetite-inhibiting hormones are the hormones in fish that signal their satisfaction (anorexigenic factor). Several external and internal factors affect the display of this physiological role in feed intake regulation in fish with regards to their specificity. As such, these factors regulate the roles of the gene either by playing opposite roles or not affect the fish at appropriate times. Below, we elaborate more and present summaries of the results of research findings on apelin as an appetite-regulating hormone in fish.

- **FEEDING ADAPTATION OF FISHES**

Different types of changes have been made in the digestive system of fish due to different diets. This change in the body's ability to take food is called feeding adaptation. The lips, mouth, teeth, gills and digestive tract are modified and adapted based on the diet. These are described below:

Modification of Lips

Eating habits can cause structural changes in the lips of fish. Different types of lip structure are described below:

1. Thin lip: Fish that eat large foods have very stiff jaws and thin, unaltered lips such as Xenentodon.

2. Thick and Fleshy lip: The fishes that take food by sucking, they have thick and fleshy type lip. Carp (Cyprinidae) have thick and fleshy lip so they can bite or suck.

3. Transformation into Hold fast Organ: Free-living Sisorid catfish in Asia, some South American catfish (Loricaridae), Loach-like Gyrinocheilid (Gyrinochilus) of Southeast Asia have sucktorial lips. Gyrinochilus has separate water entry and exit techniques in the operculum so they do not have to breathe through their mouth while they are engaged in food sucking. In parasitic lampreys (Petromyzonidae) and Hagfish (Myxinidae), the jawless sucking mouth also acts as a holdfast organ for attachment to the host and a food-extracting organ from the host. Moreover the sucking mouth of the lamprey can remove stones.

As the lips of the fish have changed due to feeding habits, so has the mouth. Such changes are seen in Gazers and Suctorial Feeders. The following are the descriptions of different types of mouth of fish:

1. Predatory Mouth: The mouth is large, the jaw is stiff and both jaws have sharp teeth. The mouth expands and swallows the prey. In freshwater shark (Wallago attu) and deep sea predatory fish such as viper fish (Chauliodus), this type of mouth is seen.

2. Sucking Mouth: This type of mouth is round, funnel shaped. There is no jaw in the downward mouth. The tongue has numerous small teeth. Example- Petomyzon marinus.

3. Absorbing mouth: This type of fish's mouth is like a tube. Such a mouth does not have teeth. The mouth is extending outwards. They eat small animals at the bottom of reservoirs as food such as pipe fish– Syngnathus.

4. Grinding mouth: This type of mlouth looks like the lips of an aquatic bird. The jaw contains hard and sharp teeth. Such fish can eat by breaking food or in pieces. Example- Xenentodon cancila

5. Plankton Feeder Mouth: This type of mouth is suitable for eating plankton. The mouth is large or medium type. Jaws are soft with no teeth in mouth. Their gill raker is densely embedded to form a sieve-like structure. Example- *Tenualosa ilisha*, *Hypophthalmicthyes molitrix, Catla catla.*

Special type of Mouth: Special type of mouths is of three types, viz

1. Half beak: In such a mouth, the lower jaw is long and the upper jaw is short. The teeth are small which are suitable for taking small foods on the surface of the water. Example: *Hyporhamphus gaimerdi*

2. Paddle like Mouth: The upper jaw of this type of fish is extended but the lower jaw is short. It moves the mud from the bottom with a spoon-shaped beak and finds small creatures and eats them. Example: Paddle fish-*Polyodon spathula.*

3. Protrusive Mouth: The pre-maxillary bones of some fish are attached to other bones in front of the skull in such a way that they can project at will. Such an enlarged mouth increases the space inside the mouth compared to other fish. This type of fish with a mouth is predatory in nature. Example: *Nandus nandus.*

Position by Mouth

Position by mouth is divided into the following distinct parts, e.g.

1. Superior Mouth: In such a mouth, the lower jaw is larger and the upper jaw is smaller. The mouth is located diagonally upwards. Such mouth can be seen on plankton-eating fish living on the surface of the water. Example: *Catla-Catla catla, Silvercarp-Hypophpthalmicthyes molitrix, Pabda catfish-Ompok pabda*

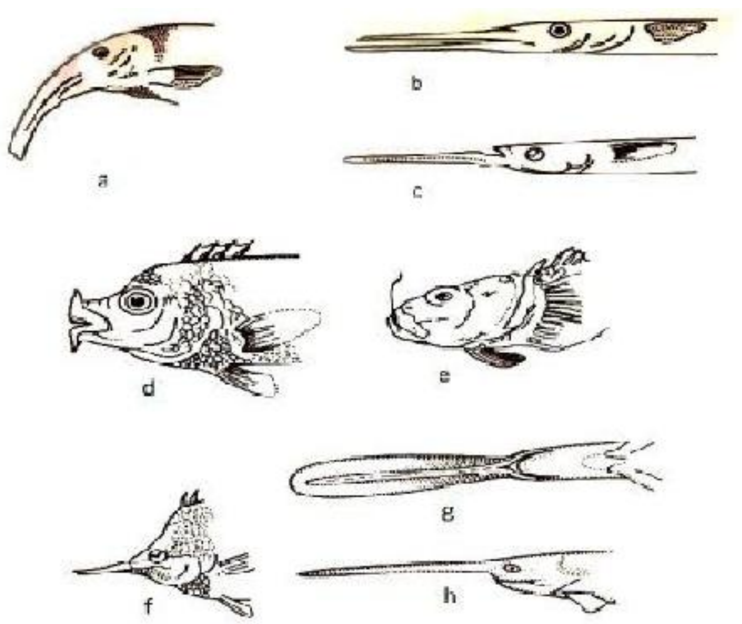


Fig.5.5.2: some adaptation in mouth of fishes: (a) Elephant fish (Gnathonemas elephas) (b)Gar fish (Strongylura longirostris) (c) Halfbeak (Hyporhamphus unifasciatus) (d) Thick- lipped mojarra(Cichasoma lobochilus) (e) Stargazar(Zalescopus tosae) (f) Longnose butterfly fish (Forcipiger longirostris) (g) and (h) Paddle fish (polyodon spathula) source: (lagler et.al.1977)

2.Terminal mouth: In this case, the position of the mouth is almost parallel to the body. Such mouth-fed fish eat surface and mid-surface food. Example: Puffer fish-Tetradon cutcutia.

3. Sub-terminal Mouth: In this case, the mouth opening is located below the upward mouth opening and slightly above the lateral mouth opening. Example: Rohu- *Labeo rohita.*

4. Inferior Mouth: In this case, the upper jaw is large and the lower jaw is very small. Such fish eat the food from the bottom. Example: *Mrigel fish – Cirhinnus cirrhosus.*

5. Ventral Mouth: The mouth of such is located on the ventral surface. Such mouth can be seen in many teleosts and elasmobranchs. Example: *Wallago attu, Scoliodon laticaudus.*

6. Semi-ventral Mouth: Such a mouth is not located in a completely ventral position. As a result of the development of fleshy lips, it has taken a ventral position. Example- *Conta conta.*

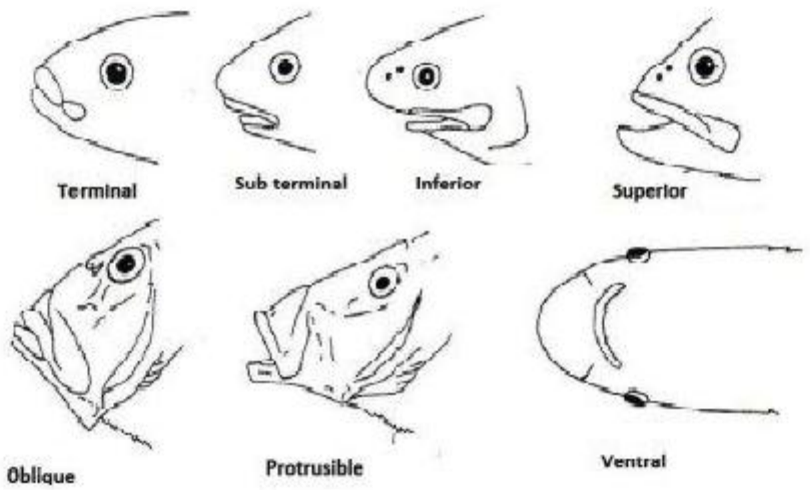


Fig.5.5.3: Showing mouth positions of different fishes

Modification in the Teeth

There have been special changes in the teeth of fish for eating. The positional and morphological changes of the teeth are significant in this case. In chondrichthyes, placoid scales are transformed into teeth. Depending on where it is found, teeth of bony fish can be divided into the following three types:

(1) jaw,

(2) mouth and

(3) pharynx.

1. Jaw Teeth

These teeth are located in the maxillary, pre-maxillary and dentine bones of fish. Such toothed fish are predatory in nature. Example: *Channa striatus*

Also the jaw teeth are divided into five types based on the shape, viz

(1) Cardiform: They are many in number, short and small but pointed. There is a pad of teeth on a bone. Such fish eat plankton, soft plants and small animals. Such teeth are found in North American catfish *(Ictaluridae), Perch (Percidae)* and *seabass (Serranidae).*

(2) Villiform teeth: Such teeth look like intestinal villi but are a little longer which helps to hold food. Such toothed fish eat zooplankton, plants and small fish. Examples: *Xenentodon cancila, Pterois miles.*

(3) Canine teeth: These teeth are like dog teeth. In most cases, they are look a venom tooth of snake. These are elongated, conical, curved, and pierced. Predatory fish have such teeth. They take small animals and small fish as food. Example- *Whitespotted moray (Gymnothorax punctatus), Deep sea viper (Chauliodus solani).*

(4) Incisor teeth: These are cutting teeth with sharp edges. In some fishes, these are human-like teeth. Such toothed fish are usually accustomed to crushing aquatic weeds, crustaceans and molluscs. E.g. *Rainbow parrot fish (Sarus guacamaia).*

(5) Molariform teeth: These teeth are suitable for grinding and crushing. These are flat and wide. Such teeth can be seen in the fish living at the bottom. Examples: *Skates (Dasyatis), Chimaera (Holocephali).*

2. Mouth Teeth

This type of tooth is seen in parasitic fish. It is funnel type mouth which does not have a jaw. There are small teeth inside the mouth. Example- *Petromyzon marinus.*

3. Pharyngeal Teeth

Different fish have a few sets of teeth of different shapes in the pharyngeal region. Such teeth are used for grinding. It is again of four types, viz:

(1) Grasping type: Such teeth are used to grasp food such as *Puntius* has such teeth;

(2) Tearing type: This type of tooth helps in breaking food. It is seen in *rudd (Scardinius);*

(3) Grinding type: This type of tooth is used for grinding food. It is found in *Cyprinus carpio.*

(4) Comb like– This type of tooth is used to filter food. It is found in golden redhorse -*Moxostoma erythrurum.*

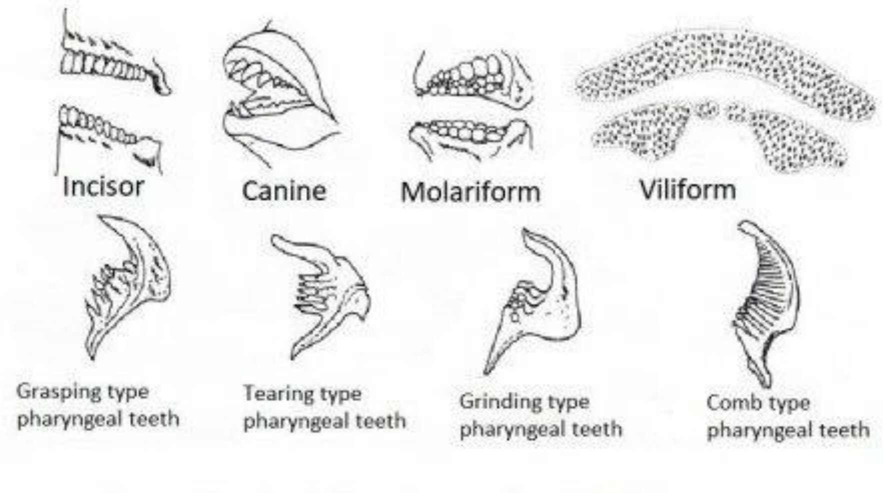


Fig.5.5.4: Showing different type of teeth in fishes

Fish Jaws

Fish have two types of jaws, the upper jaw is called the maxilla and the lower jaw is called the mandible. Fish jaws can be divided into three types based on the presence of teeth, viz:

(1) Teeth jaw: The jaws of such fish are hard and sharp-toothed. These fish eat plankton or zooplankton and small fish, such as *Xenentodon cancila.*

(2) Cut edged jaw: The jaws of this type of fish have no teeth but the edges are sharp. This type of fish eats plant by cuttings, such as grass carp – *Ctenopharyngodon idellus.*

(3)Toothless jaw: This type of fish has no tooth on jaws and they eats phytoplankton, zooplankton and aquatic plants, such as *Labeo rohita.*

- **Dentition**

There is a deep connection between eating habits and the food consumed. In predatory fish such as pike (Esox), gar (Lepisosteus) and deep sea gulper, they have sharp pointed teeth which help to catch prey. The toothless jawed fish eats plankton and periphyton (Swallowers-Saccopharyngoidae). Skates (Rajidae) and drums (Sciaenidae) have molariform teeth in the oral or pharyngeal cavity that help to eat snails, clams, oysters, crustaceans.

Razor-like incisors teeth are found in predatory fish, especially piranhas (Serrasalmus) and warm-sea barracuda (Sphyraena). Some herbivorous fish (Parrot fish-*Scaridae*) have teeth in their jaws and gills. The teeth of the jaw come together to break the food into pieces, and the crushed teeth of the pharynx turn the pieces of food into fine particles.

Plankton eaters have no teeth in their mouths. However, some omnivores do not have teeth. The number of bones is gradually increasing in predatory fish. Teeth are seen in the premaxillary bone in most fish with teeth. Similar conditions are observed in Bofin (Amia), Gar (Lepisosteus), Salmon and Trout (*Salmoninae)* and *Perciformes*. Fish with soft fins have pre-maxillary and maxillary teeth. Spiny ray-finned fish do not have maxillary teeth.

- **Modification of Gill Rakers**

The primary function of the gill rakers is to protect the gill filaments from injury. However, they also help in eating fish. Carnivorous fish *(Wallago attu, Chitala chitala (= Notopterus chitala), Channa marulias, C. striatus, Herpodon nehereus, Mystus seenghala)* have usually long hard teeth and they form rasping organs. However, in some fish such as Trichiurus, these are reduced to form small granular structures.

Muraenesox does not contain any gill rakers. In some omnivorous species such as Tor tor, Puntius sarana, P. ticto, etc., the gill rakers are short and thick. In herbivorous fishes such as *Rohu (Labeo rohita), Mrigel (Cirrhina cirrhosus), Catla (Catla catla)*, the gill raker forms a wide sieve-like organ. The mouth cavity selects food particles by filtrating water into the pharyngeal region. This condition is more developed in plankton-eating fish such as *Tenualosa ilisha, Gudusia chapra, Engraulis japonicum*. The gill rakers of these fish are long and they select zooplankton and phytoplankton as food in the mouth cavity region.

However, some fish, such as *Boleopthalmus* and *Syngnathidae*, are plankton-eating, despite the presence of decaying gill rakers. In this way, the gill raker picks up the food particles and arranges the food through the gill pouches so that the food does not go away from the mouth. This filtration efficiency increases in omnivores from carnivores and is highest in herbivores. Different fish vary in number and size of gill rakers. However, due to different ecological niches, in the fish of the same species, the gill rakers are also different.

Types of Gill Rakers

Depending on the position, gill rakers can be divided into three categories, viz.

(1) Short gill raker: This type of gill raker is usually found in predatory fish;

(2) **Medium sized gill raker**: Such gill racker exists in omnivorous fish;

(3) Large and comb like gill raker: The fishes that take food by seiving, they have this kind of gill raker.

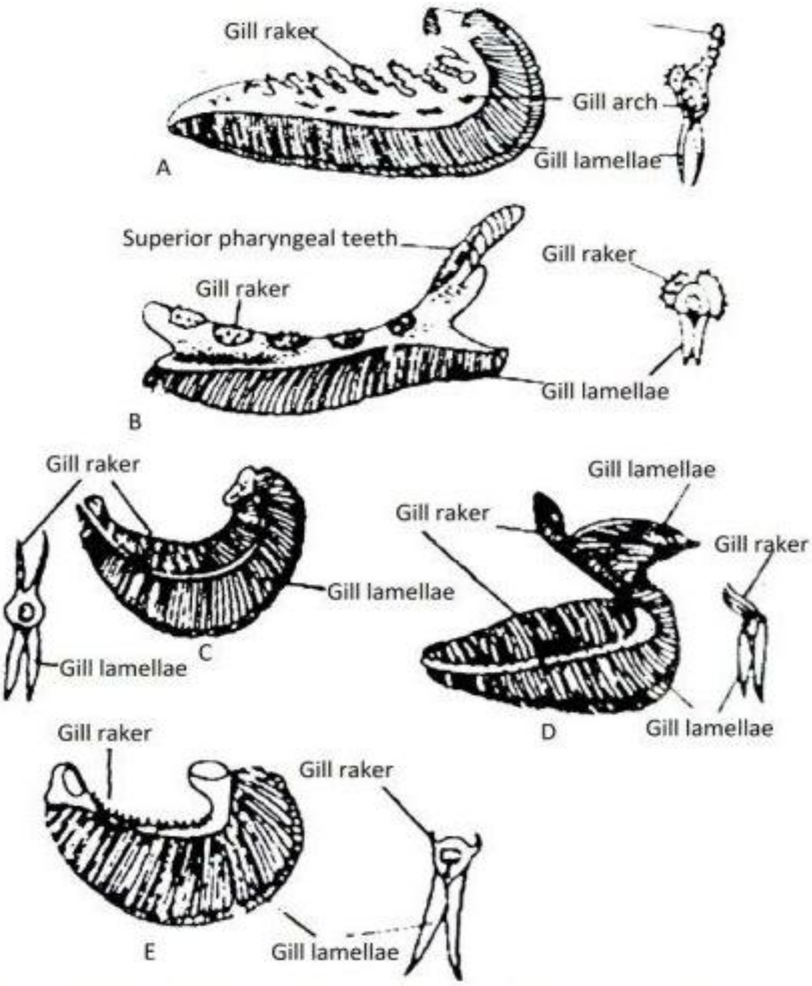


Fig.5.5.5: Showing Gill of fishes (Entire and T.S): A. Chitala chitala B. Channa marulius C. Catla cala D. Tenualosa ilisha E. Cirrhinus cirrhosus

5.6 ALIMENTARY CANAL AND ITS MODIFICATIONS IN RELATION OF FOOD AND FEEDING HABITS

Alimentary canal of fish consist of mouth, oesophagus (throat), and areas for the absorption of food components (fore and midgut) and compaction of indigestible waste material (hindgut) The structure of alimentary canal varies in different species of fishes, and is generally adapted in relation to the food and feeding habits. The variations are seen in the position of the mouth, architecture of buccopharynx, relative length of the gut, presence or absence of the stomach and pyloric caeca.

GUT AND ITS SUBDIVISIONS

The gut is a tubular structure beginning at the mouth and ending at the anus. It is commonly divided into four parts.

• The most anterior part, the head gut is most often considered in terms of its two components, the oral (buccal) and gill (branchial or pharyngeal) cavities.

• The foregut begins at the posterior edge of the gills and includes oesophagus, stomach and pylorus.

• The midgut includes the intestine posterior to the pylorus, often with no distinct demarcation posteriorly between it and the hindgut. The midgut is always the longest portion of the gut and may be coiled into complicated loops when longer than the visceral cavity

• The beginning of the hindgut is marked by an increase in diameter of the gut. The posterior end of the hindgut is the anus.

Alimentary Canal of Cartilaginous Fish (Scoliodon)

• It has a crescentic mouth on ventral side of the snout.

• The buccal cavity is lined by a thick and rough mucous membrane. A large number of dermal denticles are present in the mucous membrane, which become enlarged to form the pointed teeth on the jaws.

• Teeth are arranged in several row, one behind the other, of which only one row is functional at a time. When teeth of the first row lost, other migrate to take their place. Teeth of the Scoliodon are not used for mastication.

- **Tongue:** Simple and non muscular without any gland.
- **Pharynx:** The buccal cavity leads into the pharynx, which is perforated on each by the opening of gill pouches. Mucous lining of the pharynx is also rough due to the presence of dermal denticles in it.

- **Oesophagus:** pharynx opens into a short muscular oesophagus whose internal lining is raised into longitudinal folds.
- **Stomach:** oesophagus is followed by muscular stomach which is J shaped with a long limb (cardiac) and a shorter limb (pyloric). A small blind sac as an outgrowth at the junction of the cardiac and pyloric stomach is present. Pyloric stomach opens into muscular chamber called Bursa entiana. The opening is guarded by valve composed of circular muscle fiber.
- **Intestine:** Bursa entiana opens into the short intestine which is wide tube open posteriorly into rectum intestine have characteristic scroll valve which has 2½ turns in anticlockwise. This scroll valve check the rapid passage of food through intestine and increase its absorptive surface.
- **Rectum:** intestine is followed by rectum. One small rectal gland also opens into the rectum

  Alimentary Canal of Teleost

  Alimentary canal of *C. batrachus or M. seengala* can be consider as a typical example of teleost alimentary canal.
- **Mouth:** Lies at the anterior end of the snout and open behind into the buccal cavity. Barbels surrounding the mouth are used for the searching the food.
- **Teeth:** Numerous fine pointed teeth i.e. Maxillary, vomerine (behind upper lip) and mandibular (behind lower lip) are present. Rest of the buccophayrngeal cavity is lined with soft mucous membrane.

Pharynx: The buccal cavity leads into the pharynx, which is perforated ventro-laterally by means of oblique gill slits. Gill rakers are present in one or two rows on each gill arch and are hard and pointed structure. Gill rakers of the 1 st arch are longest while 4 to arch are smallest in size. They prevent the escape of the food through gill slits.

Gullet: Pharyngeal cavity open into oesophagus by the mean of circular aperture called gullet. A pair of bony plates present on the dorsal side just anterior to the gullet bears superior pharyngeal teeth. Similarly a pair of bony plates borne by 4 th gill arch bear inferior pharyngeal teeth. Mucous lining the posterior region of the bucco-pharynx is raised into prominent folds near the gullet. • Oesophagus: Short tube behind the gullet which opens into the stomach.

Stomach: Sac like structure with muscular walls. The distal end of the stomach continues into the intestine and the junction of the two is marked by a constriction called the pylorus guarded by a muscular sphincter. The mucous lining of the gut forms prominent folds and thick in stomach.

Intestine: intestine is of moderate length having 1 or 2 coils only. Its wider proximal part and the narrow distal part opens into a slightly wider rectum. The mucous lining of the intestine show a zig-zag pattern in proximal region and reduce and indistinct at distal part.

Rectum: Intestine is followed by rectum and opens to the exterior by anus.

Histology of different subdivisions of alimentary canal

Modification of alimentary Canal Fishes show great variation in the morphology of alimentary canal or gut in all the sub division i.e. Fore-gut, mid-gut and hind-gut.

Dentition: Carnivorous and predatory fishes have strong and pointed teeth. eg: *W. Attu, M. Seengala, C. Marulius, C. Punctatus, C. Straitus, Notopterus chitala, Harpodon neherius etc. N. Chitala and N. Notopterus* posses teeth on the tongue also. **Herbivorous species,** teeth are completely absent from the jaws and palate. • In some omnivore like *C. batrachus* posses fine teeth on jaws and palate which other like *T. tor, P. sarana, C. reba, C. carpio* teeth are absent from the jaws and plate. **In plankton feeder** like *H. hilsa and Gadusia chapra* have complete edentulous buccopharynx.

- **Buccopharynx:** In carnivorous species there is no clear demarcation between buccal cavity and pharyngeal cavity. In herbivore, there is clear demarcation between the buccal and pharyngeal cavity.
- **Gill Rakers:**In carnivorous and predatory fishes i.e. W. attu, M. seengala, N. chitala, C. marulius, H. neherius, gill rakers are long, hard and teeth like. In omnivorous species as the T. tor, P. sarana, the gill rakers are short stumpy structure. In herbivorous fishes i.e. L. rohita, L. gonius gill rakers form a broad sieve across the gill slits.In plankton feeder like C. catla, H. hilsa, G. chapra etc., gill rakers are fairly long and thin and form a fine sieve to retain zoo and phyto-planktons.
- **Taste buds and mucus secreting cells:** In herbivore and omnivore fishes, a soft cushiony pad is present in the roof of the buccal cavity which has large number of papillae bearing taste buds and mucus secreting cells. Large number of taste buds are present in C. catla, Puntius spp., Tor spp., C. mrigala, Schizothorax, In carnivorous species like Channa and Mystus taste buds are less or absent
- **Oesophagus:**In herbivorous and some omnivorous like *L. rohita, C. carpio, C. mrigala, P. saphore, T. tor, L. calbasu,* the oesophagus is short and narrow. In carnivorous and predatory fishes i.e. *W. attu, M. seenghala, Channa* spp. Oesophagus is much longer and wider.
- **Stomach:**In carnivorous fish, the stomach has prominent, thick mucosal folds and its wall are thick. In plankton feeder as *Hilsa, Gadusia, Mugil,*the posterior region of the stomach reduce in size and greatly thickened so as to look like a gizzard.Some fishes (mostly carps) have no stomach so no acid phase of digestion occurs like *Labeo spp., C. mrigala, C. catla, Tor tor, P. saphore, P. sarana,* etc.

- **Intestinal Bulb:**some fishes do not possess a true stomach and anterior part of the intestine become swollen to form a sac like structure called intestinal bulb. in these fishes oesophagus is followed by intestinal bulb and this is the special feature of *cyprinids as Labeo spp., C. mrigala, C. catla, T. tor, P. saphore, P. sarana* etc
- **Intestine:**The main variation or modification in intestine is the length only. In most of the carnivore, length of intestine is short. In most of herbivore and plankton feeder, length of intestine is very long. In omnivore, intestine is of moderate length.
- **Pyloric Caeca:** several finger like outgrowth at anterior part of the intestine or in the region of pylorus are called pyloric caeca. Pyloric caeca are present in species like Notopterus, Channa, Hilsa, Harpodon, Mastacembelus. Pyloric caeca are absent in stomach less fish species like IMC.They are also absent in Wallago, Mystus. They vary in number and size.

5.7 DIGESTION AND ABSORPTION

The digestive system, in a functional sense, starts at the mouth, with the teeth used to capture prey or collect plant foods. Mouth shape and tooth structure vary greatly in fishes, depending on the kind of food normally eaten. Most fishes are predacious, feeding on small invertebrates or other fishes and have simple conical teeth on the jaws, on at least some of the bones of the roof of the mouth, and on special gill arch structures just in front of the esophagus. The latter are throat teeth. Most predacious fishes swallow their prey whole, and the teeth are used for grasping and holding prey, for orienting prey to be swallowed (head first) and for working the prey toward the esophagus. There are a variety of tooth types in fishes. Some fishes, such as sharks and *piranhas*, have cutting teeth for biting chunks out of their victims. A shark's tooth, although superficially like that of a *piranha*, appears in many respects to be a modified scale, while that of the piranha is like that of other bony fishes, consisting of dentine and enamel. Parrot fishes have beaklike mouths with short incisor-like teeth for breaking off coral and have heavy pavementlike throat teeth for crushing the coral. Some catfishes have small brushlike teeth, arranged in rows on the jaws, for scraping plant and animal growth from rocks. Many fishes (such as the *Cyprinidae or minnows*) have no jaw teeth at all but have very strong throat teeth.

Some fishes gather planktonic food by straining it from their gill cavities with numerous elongate stiff rods (gill rakers) anchored by one end to the gill bars. The food collected on these rods is passed to the throat, where it is swallowed. Most fishes have only short gill rakers that help keep food particles from escaping out the mouth cavity into the gill chamber.

Once reaching the throat, food enters a short, often greatly distensible esophagus, a simple tube with a muscular wall leading into a stomach. The stomach varies greatly in fishes, depending upon the diet. In most predacious fishes it is a simple straight or curved tube or pouch with a muscular wall and a glandular lining. Food is largely digested there and leaves the stomach in liquid form.

Between the stomach and the intestine, ducts enter the digestive tube from the liver and pancreas. The liver is a large, clearly defined organ. The pancreas may be embedded in it, diffused through it, or broken into small parts spread along some of the intestine. The junction between the stomach and the intestine is marked by a muscular valve. Pyloric ceca (blind sacs) occur in some fishes at this junction and have a digestive or absorptive function or both.

The intestine itself is quite variable in length, depending upon the fish's diet. It is short in predacious forms, sometimes no longer than the body cavity, but long in herbivorous forms, being coiled and several times longer than the entire length of the fish in some species of South American catfishes. The intestine is primarily an organ for absorbing nutrients into the bloodstream. The larger its internal surface, the greater its absorptive efficiency, and a spiral valve is one method of increasing its absorption surface.

Sharks, rays, chimaeras, lungfishes, surviving chondrosteans, holosteans, and even a few of the more primitive teleosts have a spiral valve or at least traces of it in the intestine. Most modern teleosts have increased the area of the intestinal walls by having numerous folds and villi (fingerlike projections) somewhat like those in humans. Undigested substances are passed to the exterior through the anus in most teleost fishes. In lungfishes, sharks, and rays, it is first passed through the cloaca, a common cavity receiving the intestinal opening and the ducts from the urogenital system.

- As in other vertebrates, the alimentary tract can be divided into 1) The anterior part consists of the mouth, buccal cavity, and pharynx.
- 2. The posterior part consists of the foregut (esophagus and stomach), midgut or intestine, and hindgut or rectum.
- Voluntary striated muscle extends from the buccal cavity into the esophagus, involuntary smooth muscle from the posterior portion of the esophagus through the large intestine. Barrington (1957), Kapoor *et. al.* (1975), and Fange and Grove (1979) provide detailed accounts of the alimentary tracts of fishes.
- In hagfishes and lampreys, the absence of true jaws is correlated with the absence of a stomach.
- Presumably, the evolution of jaws permitted capture of larger prey, making a storage organ, the stomach, highly advantageous. Both hagfishes and lampreys have a straight intestine, but the surface area of the intestine is increased in the lampreys by the typhlosole, a fold in the intestinal walls.

- Chondrichthyes increase the surface area of the intestine by means of a spiral valve, a sort of a spiral staircase inside the intestine

Mouth in Fishes

- Mouth is the anterior opening of alimentary canal .
- Most fish mouth fall into first three general types:

  1 .Superior mouth type: Some species with a superior mouth have an elongated lower jaw that functions much like a scoop.Archers, half-beaks, and hatchetfish and Catla are all examples of species of aquarium fish that have a superior mouth.

  2. Terminal mouth type: Most fish that feed on other fish have terminal mouths, which are often hinged to allow them to accommodate the action of snatching and swallowing another fish. They may also possess specialized teeth, and in some cases an additional jaw. Moray eels are one type of species that have a pharyngeal jaw placed well back in their throat. Most barbs, cichlids, gouramis and tetras have terminal mouths

3. **Inferior or sub terminal mouth type:**Also called a sub-terminal or ventral mouth, the inferior mouth is turned downward. The lower jaw is shorter than the upper jaw, and the jaw will often be protrusible.

Fish with inferior mouths are usually bottom feeders and often possess barbels that assist in locating food particles. Most members of the catfish family and Mrigal have inferior jaws, and many of them also have a sucker mouth as well.

The diet of fish with inferior mouths includes algae, invertebrates (such as snails), as well as detritus and any food that falls to the bottom. The mouth of cartilaginous fishes is ventral.e.g. Sharks, Rays and Skates.

4. Protrusible Mouth

5. Sucker mouthsare a common feature in fish with inferior mouths. Catfish, such as the popular plecostomus (which literally translates to folded mouth), use a sucker mouth to rasp algae off driftwood or rocks. A greatly elongated snout is another kind of mouth adaptation. This type of mouth allows the fish to poke into small crevices and holes to find food. They may also use this mouth to dig through the substrate to reach buried food treasures. Some surface feeding fish also have an elongated mouth that allows them to scoop insects and food particles from the surface.Freshwater species with elongated mouths include the halfbeaks.

6. The beak mouthis an interesting, but less common, mouth variation; it's also known as a rostrum. In this design, the mouth consists of two very hard pieces that are hinged and come together in a scissor-like fashion. This allows them to crush hard shells of invertebrates. Pufferfish, both freshwater and saltwater species, and Saltwater.

7. Stomach : Stomach acquire different shapes according to the availabilityof space in the body cavities of different fishes.

- Anterior – cardiac stomach
- Stomach
- posterior – pyloric stomach

A true stomach is present in the carnivorous and predatory fishes e.g. *Channa striatus, Mystus seenghala* etc .

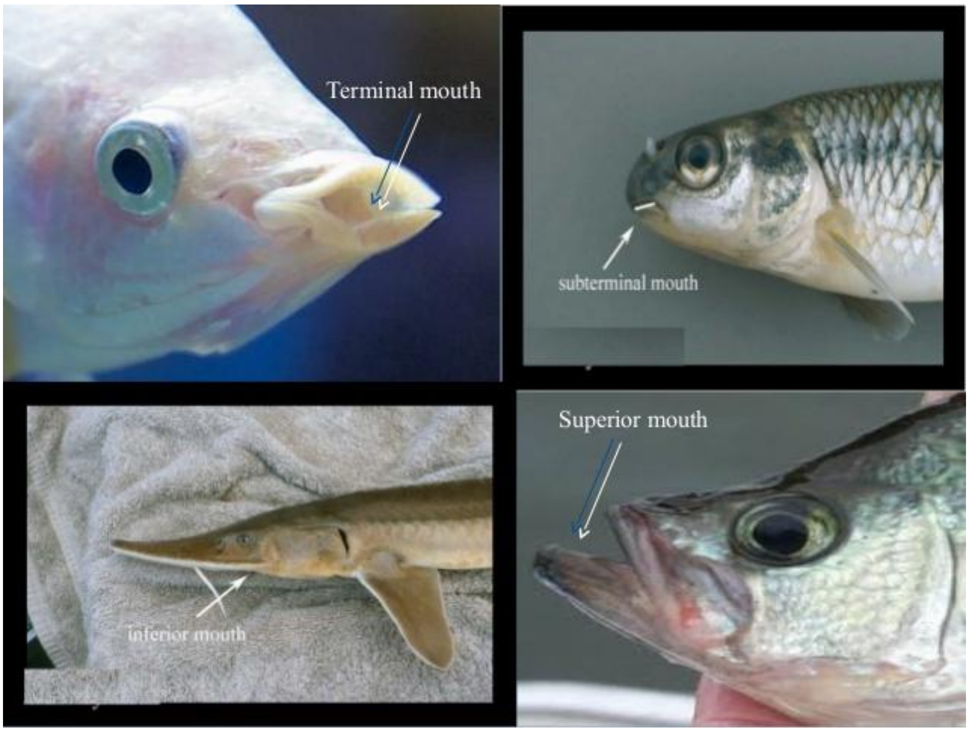
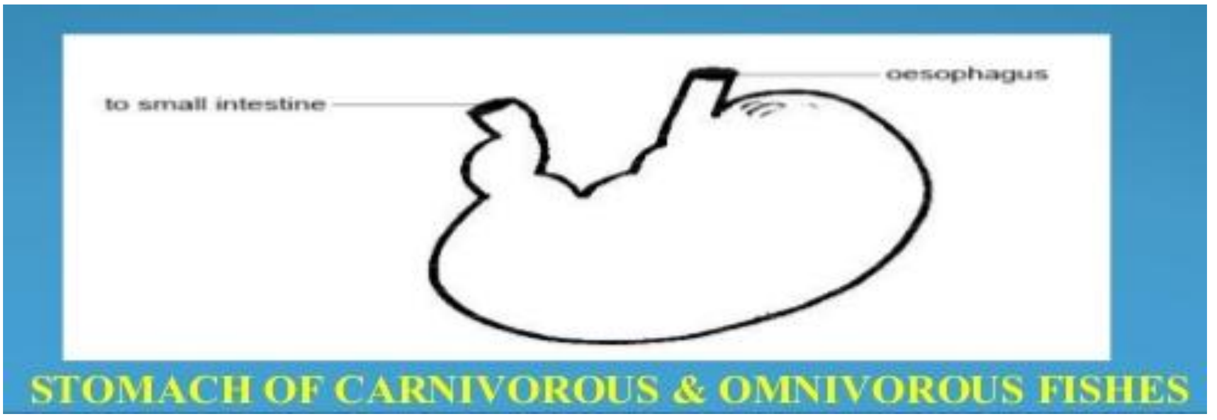


Fig. 5.7.1 different type of moth in fishes

- **Intestinal bulb (Stomachless Fishes):**
- All the fishes do not possess a true stomach as it is almost absent in various herbivorous fishes like *Labeo rohita,Catla catla* etc.
- About 15% of teleosts, including *cyprinids*, have no stomach and no region of low pH or pre-digestion. Anterior portion of intestine has some storage function, intestine in these species is usually very long compared to, say, a trout (Rombout, et al. 2011).

- In such fishes, the anterior part of the intestine is swollen to form a sac like structure called intestinal bulb.
- Carnivorous fishes: Stomach is generally sac-like and thick walled in Carnivorous and predatory fishes.
- Omnivorous fishes: Stomach of omnivorous fishes is also sac like .e.g. *Puntius sophore,Cyprinus carpio* etc.
- In some fishes like *Hilsa hilsa,Gudusia chapra*, stomach is reduced in size but is greatly thickened to become gizzard like for trituration of food.

Fig.5.7.2 Stomach



- **Pyloric caeca:** Anterior part of the intestine give rise to a number of finger-like outgrowths calledpyloric or intestinal caeca. Pyloric caeca serve as accessory food reservoirs .Histologically, intestinal caeca resembles the intestine and probably serve to enhance the absorptive area.
- **Intestine** :The part of alimentary canal that follows the stomach is called intestine and is divided into two parts:
- Anterior part : small intestine
- Posterior part : large intestine
- The small intestine just behind the stomach receives ducts from the liver and pancreas is called as duodenum while rest part is called ileum There is no clear cut demarcation between the small intestine and large intestine .
- The length of the intestine depends upon the feeding habit of the fish.
- **Herbivorous fishes:**Intestine is often elongated and arranged in many folds in case of herbivorous fishes.Longer intestines are of great advantage to herbivorous fishes as they retain food for long period of time to ensure digestion.
- **Carnivorous fishes** : It is shortened in carnivores such as in *Wallogo attu, Mystus seenghala* because flesh can be digested more readily than the plant based food stuff.

Fig.5.7.3Digestive tract of Carnivorous fish

Fig.5.74:

Structures of the Digestive tractof Herbivorous fish:(A) Esophagus, (B) Stomach, (B1) Cardiac Stomach, (B2) Fundic Stomach, (B3)Pyloric Stomach, (C) Pyloric Caeca, (D) Anterior Intestine, (E) Midintestine,and (F)Posterior Intestine.

Omnivorous fishes:

Intermediate length of the gut is found in case of omnivorous fishes e.g. *Puntius sophore* etc.The intestinal bulb of *Labeorohita* is about 25cm,the small intestine about 8m and the large intestine about a meter in length.

ALIMENTARY CANAL IN BONY FISH (*Lamprey and Shark*)

Rectum : It is not usually distinguishable externally but an ileo-recta valve is present in few species of fish to demarcate it from the intestine e.g. Tetradon Histologically ,the mucosal folds of the rectum differ from the intestine in being shorter and broader, possess a large number of mucus secreting cells produce copious mucus to lubricate waste food and aid in easy defecation.

Digestive glands :The digestive system consists of alimentary canal and its associated glands. The digestive tube also contains numerous intramural glands which provide the tube by lubricating mucus, enzymes, water, etc.

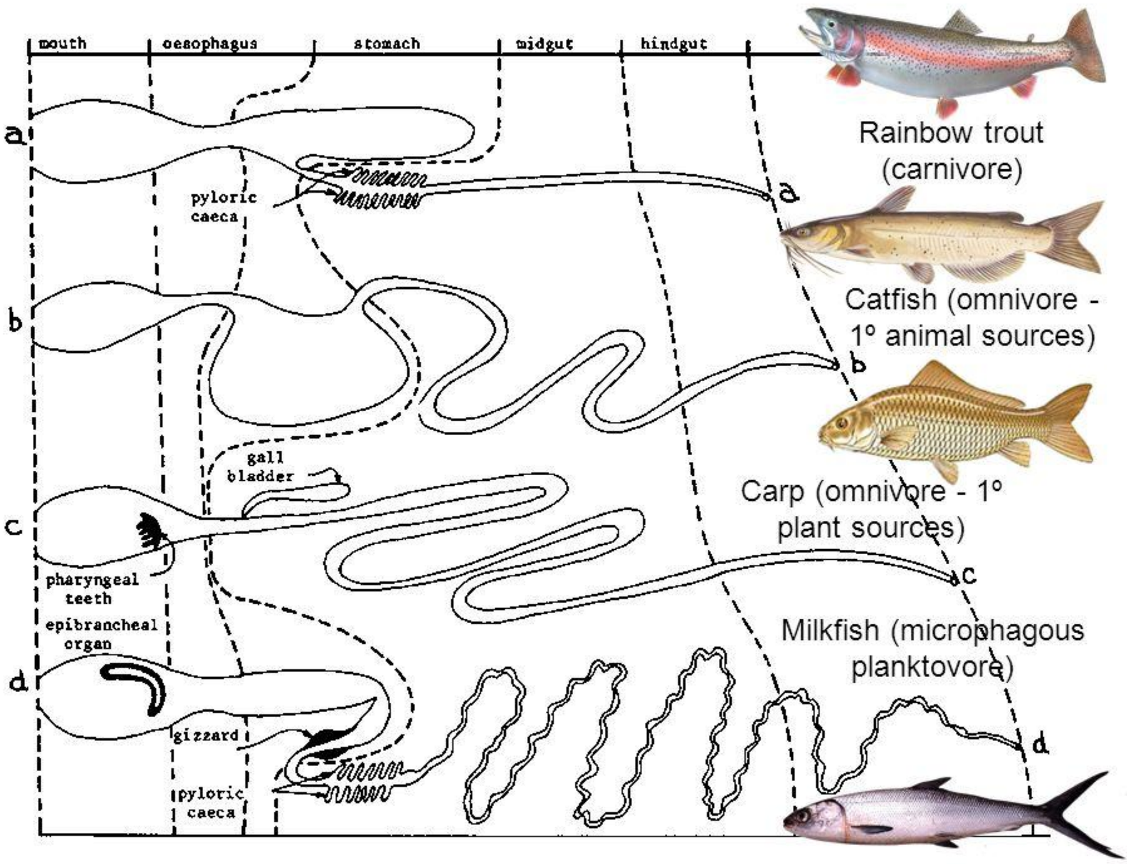


Fig.5.7.5: Alimentary canal in bony fish

- The extramural glands are liver, pancreas and gall bladder. The liver is present in all fishes.
- The pancreas which is exocrine and endocrine organ, may be a discrete organ or it may be diffused in the liver or in the alimentary canal.
- In sharks and rays (Elasmobranchii) pancreas is relatively compact and usually well developed as a separate organ, often two lobed, but in teleosts, the pancreas is diffused in the liver to form hepatopancreas.
- It is also diffused in the alimentary canal in a few fishes. It is also present in the mesenteric membranes surrounding the intestine and liver.
- The gall bladder is vestigeal in deep sea fishes but it is prominent in other fishes.While passing through the alimentary canal, the food is broken down physically and chemically and ultimately solubilized so that degraded products can be absorbed. The absorption occurs chiefly through the wall of intestine.

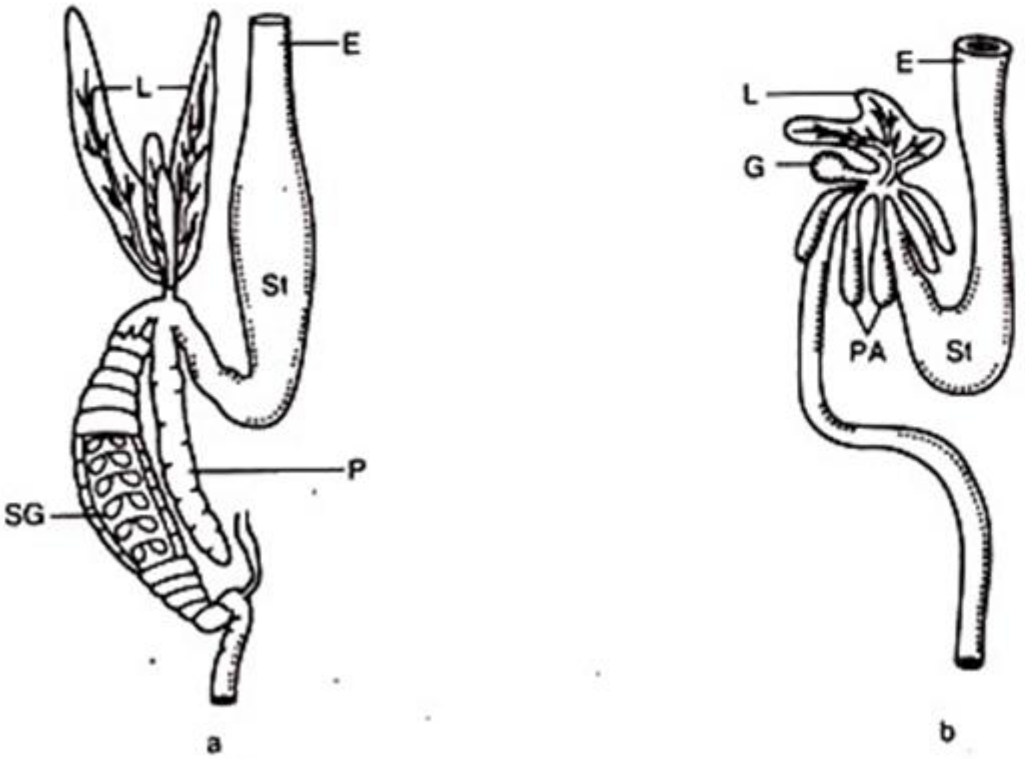


Fig.5.7.6: Diagram of Alimentary canal of (a) Elasmobranch, (b) Teleost. E, oesophagus; G, gallbladder, L, liver; P, pancrease; PA, pyloric appendices; SG, spiral gut; St, stomach.

Two main digestive glands in Fish :

1. Pancreas: pancreas is a diffuse gland, but is well developed around the blood vessels between the lobes of the liver.

Pancreas has two digestive functions:

1. Source of exocrine secretion into the intestine.
2. Endocrine secretion of the hormones insulin and glucagon .

3. **Liver:** Liver is a bilobed gland usually yellowish brown in color.The liver in fish produces bile which is stored in the gall bladder. Key storage of food energy in the form of glycogen.

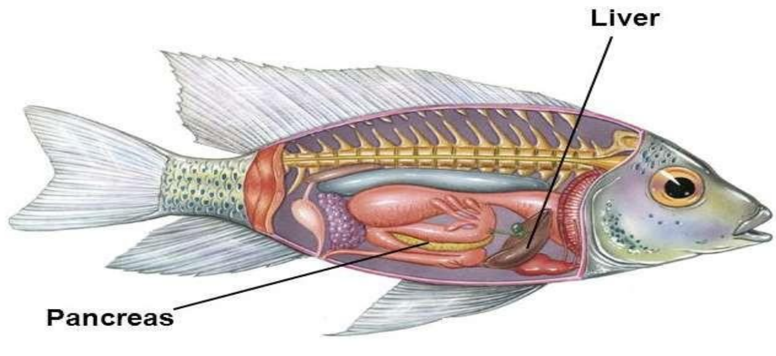


Fig.5.7.7: Digestive glands in fish

Feeding adaptaions in fishes

Various structures have been modified according to the nature of the food and feeding habits of the fish.

- Position and shape of the mouth.
- Dentition.
- Lips may become cornified as in case of *Labeo* ,granular or papillated.
- Taste buds and mucus secreting cells .
- Structure of pharynx and gill rakers have also undergo modifications according to the feeding habit of the fish.
- Relative length of the gut (RLG).
- The structure of the alimentary canal varies in different species of fishes,and is generally adapted in relation to the food and feeding habit.
- The variations are seen in the position of the mouth,architecture of the buccopharynx,relative length of the gut,presence or absence of the stomach and pyloric caecae.

5.8 GENERAL CHARACTERISTICS, FOOD AND FEEDING HABITS OF FRESH WATER FISHES

Freshwater fish are creatures that belong to the group of vertebrates, which live in the depths **of rivers, lakes, among other freshwater channels around the world.** They are capable of withstanding **large temperature changes** due to anatomy of their body.

They have special gills that help them regulate their temperature in the water, their body is usually **covered by scales** that regulate low temperatures.

In the case of the freshwater fish, their anatomy depends on the water where they are developing. Since not all waters are the same, **some are denser** than others with which each type of fish adapts little by little.

Fig.5.8.1:Freshwater fishes

They have **the same body aspect** as most vertebrates, their characteristics may vary depending on the species to which they belong, their body **is made up of a head, trunk or abdominal area** and a tail.

Their head contains branchial areas which allow them to store **the greatest amount of oxygen** and to be able **to breathe properly in the water**.

It’s worth mentioning that their trunk or abdomen houses **most of their organs** where a pair of fins can also be seen which give them **greatest possible mobility in the water.**

The tail represents another **extra complement to its anatomy**, since in the company of the dorsal fins in the trunk area are the ones **that provide all the movement** to freshwater fish, allowing them to reach the necessary speed to move along and width of the waters where they coexist.

Their skin like other vertebrates contains **special characteristics, since** most freshwater fish are covered **by scales** which are what allow them to resist **the different temperature changes** to which they **are continuously exposed.**

Although not all species have scales on their bodies some freshwater fish species contain **another type of structure** very similar to scales that performs the same function.

The freshwater fish’ diet only depends on what is in its habitat and the nutrients **that they provide for them;** and therefore it causes that the feeding habits of the fish are **very diverse** and can vary according to the case.

The diet can also vary according to the species **that is being treated,** since there **are diversity of families** that feed on various types of food in the water, be they carnivores, herbivores, among other categories

The food and feeding habits of fish is important and vital need for production of the fish. Food and feeding habits of fish are important biological factors for selecting a group of fish for culture in ponds to avoid competition for food among themselves and live in association and to utilize all the available food (Dewam and Saha, 1979). So, the knowledge of food and feeding habits help to select such species of fish for culture and produce an optimum yield by utilizing all the available potential food of the water bodies without any competition. Feeding is the dominant activity of the entire life cycle of fish (Royce, 1972). The success on good scientific planning and management of fish species largely depends on the knowledge of their biological aspects, in which food and feeding habits include a valuable portion. Therefore, the study of food and feeding habit of freshwater fish species is a subject of continuous research because it constitutes the basis for the development of a successful fisheries management programme on fish capture and culture (Oronsaye and Nakpodia, 2005). According to Sipauha-Tavares and Braga (1999), nature offers great diversity of organisms used as food by the fishes and these differ in size and taxonomic group. It is virtually impossible to gather sufficient information of food and feeding habit of fish in their natural habitat without studying its gut contents

The inland water bodies consist of small aquariums to nursery ponds, canals, beels, haor, baors (oxbow-lake), rivers, streams, flooded lands, etc. These are called freshwater basins. The more diverse fish types are found in these water bodies. The shape, nature, feeding habits, color, etc. vary from species to species. Their cultivation system is also different. It is important to have scientific knowledge about the nature of fish, feeding habits, diseases and so on to cultivate fish through the choice using suitable control measures. Food and feeding habits of fish is very important factor that helps to choose the fish type for cultivation.

Fish play an important role in the development of a nation. Apart from being a cheap source of highly nutritive protein, it also contains other essential nutrients required by the body.The food fish for the world population is produced from both aquaculture and capture fisheries. The fish consumed by human can either be freshwater or marine fish . Feeding is the dominant activity of the entire life cycle of fish . Therefore, the study of food and feeding habits of a fish is very important. This is also essential for any fishery management. Food and feeding habit of fish are important biological factors for selecting a group of fish for culture in ponds to avoid competition for food among themselves and live in association and to utilize all the available food . The knowledge of food and feeding habit help to select such species of fish for culture and produce an optimum yield by utilizing all the available potential food of the water bodies without any competition. So, the study of food and feeding habit of freshwater fish species is a subject of continuous research because it constitutes the basis for the development of a successful fisheries management programme on fish capture and culture . Study of dietary habits of fish is based on stomach content analysis which is widely use in fish ecology as an important means of investigating tropic relationship in the aquatic communities. Understanding the stomach content of fish is useful in guiding towards formulation of artificial diets in fish culture . It is virtually impossible to gather sufficient information of food and feeding habit of fish in their natural habitat without studying its gut contents . The length of the gut of a species of fish or any other animal, reflects its diet and the percentage composition of food items present in the stomach also showed the feeding habits of fish.

Analysis of content in the stomach and features of the alimentary system provide information on food, feeding habits and selective feeding, if any, in fishes. So food and feeding habit of the fish were determined on the basis of stomach contents and relative length of alimentary canal.

5.9 SUMMARY

The digestive system, in a functional sense, starts at the mouth, with the teeth used to capture prey or collect plant foods. Mouth shape and tooth structure vary greatly in fishes, depending on the kind of food normally eaten. Most fishes are predacious, feeding on small invertebrates or other fishes and have simple conical teeth on the jaws, on at least some of the bones of the roof of the mouth, and on special gill arch structures just in front of the esophagus. The latter are throat teeth. Most predacious fishes swallow their prey whole, and the teeth are used for grasping and holding prey, for orienting prey to be swallowed (head first) and for working the prey toward the esophagus. There are a variety of tooth types in fishes. Some fishes, such as sharks and piranhas, have cutting teeth for biting chunks out of their victims. A shark’s tooth, although superficially like that of a piranha, appears in many respects to be a modified scale, while that of the piranha is like that of other bony fishes, consisting of dentine and enamel. Parrot fishes have beaklike mouths with short incisor-like teeth for breaking off coral and have heavy pavementlike throat teeth for crushing the coral. Some catfishes have small brushlike teeth, arranged in rows on the jaws, for scraping plant and animal growth from rocks. Many fishes (such as the Cyprinidae or minnows) have no jaw teeth at all but have very strong throat teeth.

Some fishes gather planktonic food by straining it from their gill cavities with numerous elongate stiff rods (gill rakers) anchored by one end to the gill bars. The food collected on these rods is passed to the throat, where it is swallowed. Most fishes have only short gill rakers that help keep food particles from escaping out the mouth cavity into the gill chamber.

Once reaching the throat, food enters a short, often greatly distensible esophagus, a simple tube with a muscular wall leading into a stomach. The stomach varies greatly in fishes, depending upon the diet. In most predacious fishes it is a simple straight or curved tube or pouch with a muscular wall and a glandular lining. Food is largely digested there and leaves the stomach in liquid form.

Between the stomach and the intestine, ducts enter the digestive tube from the liver and pancreas. The liver is a large, clearly defined organ. The pancreas may be embedded in it, diffused through it, or broken into small parts spread along some of the intestine. The junction between the stomach and the intestine is marked by a muscular valve. Pyloric ceca (blind sacs) occur in some fishes at this junction and have a digestive or absorptive function or both.

The intestine itself is quite variable in length, depending upon the fish's diet. It is short in predacious forms, sometimes no longer than the body cavity, but long in herbivorous forms, being coiled and several times longer than the entire length of the fish in some species of South American catfishes. The intestine is primarily an organ for absorbing nutrients into the bloodstream. The larger its internal surface, the greater its absorptive efficiency, and a spiral valve is one method of increasing its absorption surface.

Sharks, rays, chimaeras, lungfishes, surviving chondrosteans, holosteans, and even a few of the more primitive teleosts have a spiral valve or at least traces of it in the intestine. Most modern teleosts have increased the area of the intestinal walls by having numerous folds and villi (fingerlike projections) somewhat like those in humans. Undigested substances are passed to the exterior through the anus in most teleost fishes. In lungfishes, sharks, and rays, it is first passed through the cloaca, a common cavity receiving the intestinal opening and the ducts from the urogenital system.
Food and feeding pattern of fish is very important factor that helps to choose the fish type for cultivation. It helps to avoid clash for getting food among them in different water levels. Fishes are carnivorous, herbivorous or omnivorous however a large portion of them are exceptionally adaptable in their feeding habits and use the promptly available diet. Just a few fish groups are strictly herbivorous or carnivorous and the available food helps to decide if it will be eaten by the fish.

5.10: TERMINAL QUESTIONS AND ANSWERS

1. ………………… are a cheap natural sources of energy.

a. Carbohydrates b. Lipids c. Proteins d. Fibres

2. ………………….. Fish species have poor ability to digest carbohydrates.

a. Herbivorous b. Carnivorous c. Ominivorous d. Euryphagus

3. Deficiency of vitamin ………………… results in metabolic disorders and spinal deformities in fish.

a. C b. A c. B d. K

4. Fishes feeding on a variety of foods are called as ………………. fishes.

a. Stenophagic b. Monophagic c. Euryphagic d. Carnivorous

5. Fishes feeding on a few selected types of foods are called as ………………. fishes.

a. Stenophagic b. Monophagic c. Euryphagic d. Carnivorous

6. Fishes feeding on single type of food are called as ………………. fishes.

a. Stenophagic b. Monophagic c. Euryphagic d. Carnivorous

7. ………………… type of food rarely enters the gut of fishes.

a. Basic b. Secondary c. Incidental d. Obligatory

8. ………………… type of food is usually consumed by fishes and forms the main part of gut content.

a. Basic b. Secondary c. Incidental d. Obligatory

9. ………………… type of food is frequently found in gut of fishes.

a. Basic b. Secondary c. Incidental d. Obligatory

10. ………………. type of food is consumed by fishes only in the absence of basic food.

a. Basic b. Secondary c. Incidental d. Obligatory

11. What are the factors that influence the feeding Behaviour of fish?

12. How does feeding rate affect the growth rate in fish?

13. What type of digestive system do fish have?

14. What is the function of fish stomach?

15. What is the main organ of digestion in the fish?

16. How do fishes digest absorb and excrete?

17. Why is supplementary food needed in culture fishes?

18. What are the components of artificial complete diet for fish?

19. What are the adaptation which make the fish move in water?

20. What are the four types of feeding behavior of fish in their natural habitat?

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UNIT: 6 CIRCULATORY SYSTEMS

CONTENTS

6.1 OBJECTIVES

Five (5) Major Functions of the Cardiovascular System

- Oxygen and Carbon Dioxide Transport.
- Nutrient and Waste Product Transport.
- Disease Protection and Healing.
- Hormone Delivery.
- Body Temperature Regulation.

The function of the circulatory system is to distribute nutrients, oxygen and hormones to all parts of the body and remove the metabolic waste which are carried to the excretory organs.The circulatory system is made up of two anatomically defined, intercommunicated circuits the blood, arterial- venous or primaryvascular system, through which blood flows, and the secondary vascular system or lymphatic system, through which lymph flows.

In most animals, the circulatory system is used to transport blood through the body. Some primitive animals use diffusion for the exchange of water, nutrients, and gases. However, complex organisms use the circulatory system to carry gases, nutrients, and waste through the body. Circulatory systems may be open (mixed with the interstitial fluid) or closed (separated from the interstitial fluid). Closed circulatory systems are a characteristic of vertebrates; however, there are significant differences in the structure of the heart and the circulation of blood between the different vertebrate groups due to adaptions during evolution and associated differences in anatomy. Fish have a two-chambered heart with unidirectional circulation. Amphibians have a three-chambered heart, which has some mixing of the blood, and they have double circulation. Most non-avian reptiles have a three-chambered heart, but have little mixing of the blood; they have double circulation. Mammals and birds have a four-chambered heart with no mixing of the blood and double circulation.

Fishes are cold-blooded aquatic vertebrates and can be found in both saline and fresh water. The circulatory system of fishes is responsible for transporting blood and nutrients throughout the body. It has a **closed circulatory system**, i.e. blood travels across the body through the network of blood vessels. Fish heart carry only deoxygenated blood that is why it is called as venous heart.

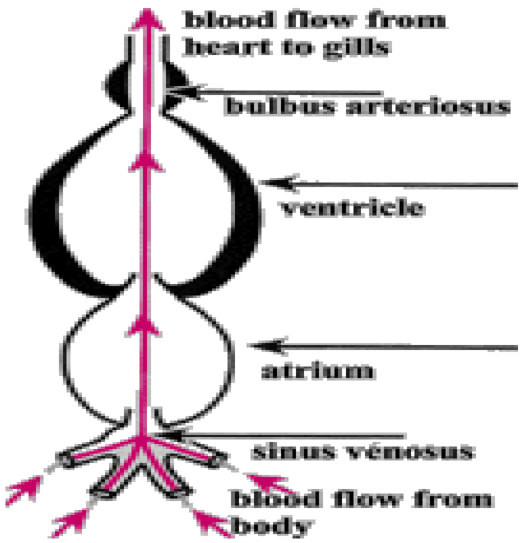
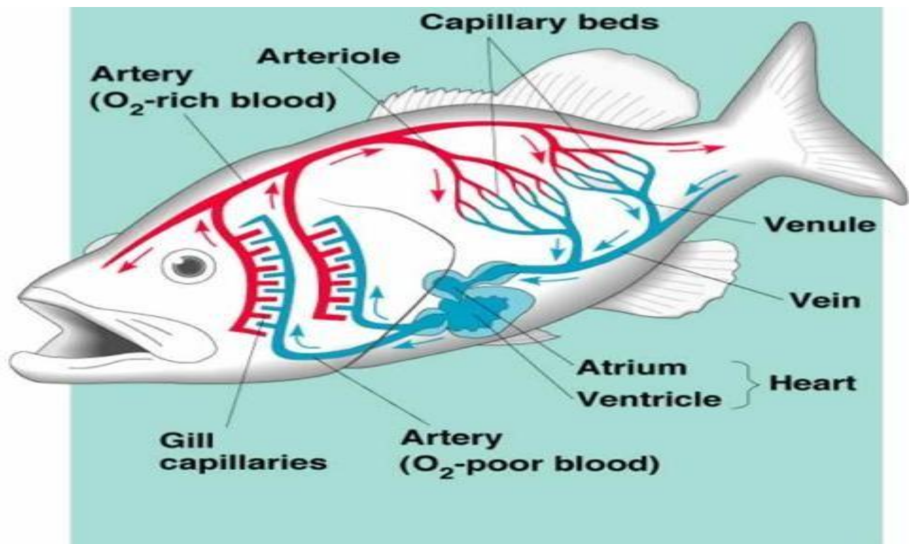


Fig. 6.1. Showing two chambered heart of fish



Fish have a single circuit for blood flow and a two-chambered heart that has only a single atrium and a single ventricle. The atrium collects blood that has returned from the body and the ventricle pumps the blood to the gills where gas exchange occurs and the blood is re-oxygenated; this is called **gill circulation**.

Fig.6.2: Gill circulation

6.3 BLOOD VASCULAR SYSTEM: STRUCTURE OF THE HEART

There are 3 basic type of heart found in animals: a 2 chambered heart, a 3 chambered heart, and a 4 chambered heart. Fish have 2 chambers, one atrium and one ventricle. Amphibians and reptiles have 3 chambers: 2 atria and a ventricle. Crocodiles are the one reptilian exception, as they have 4 chambers (2 atria, 2 ventricles). Birds and mammals have 4 chambers (2 atria and 2 ventricles).

Two type of circulatory system found in animal closed circulatory systemand Open circulatory system. Vertebrates, and a few invertebrates, have a closed circulatory system. Closed circulatory systems have the blood closed at all times within vessels of different size and wall thickness. In this type of system, blood is pumped by a heart through vessels, and does not normally fill body cavities. The open circulatory system is common to molluscs and arthropods. Open circulatory systems (evolved in crustaceans, insects, mollusks and other invertebrates) heart pump blood into a hemocoel with the blood diffusing back to the circulatory system between cells. Blood is pumped by a heart into the body cavities, where tissues are surrounded by the blood

The circulatory system of fish is quite simple and consists of two main parts: the heart and the system of pipes (veins, arteries and capillaries) that carry blood throughout the body. Every organ and cell in the fish's body is connected to this system, which serves a wide variety of purposes.

Heart is a simple muscular structure that is located below the pharynx and immediately behind the gills. It is enclosed by the pericardial membrane or pericardium. But in teleosts, it is relatively anteriorly placed than in the elasmobranches. In most of the fishes, the heart consists of an atrium, a ventricle, a sac-like thin walled structure known as sinus venosus and a tube, known as bulbusarteriosus. Inspite of containing four parts, the heart of a fish is considered two-chambered.

- **Sinusvenosus:**Thefirstchamberiscalledthe**Sinusvenosus,**itisthepreliminarycollectingchamber.I nteleostsit is filled from two major veins called the hepatic veins andthe left and right branches of the Curvierian ducts which inturn collect blood from the paired (left and right) lateral veinsthe inferior jugulars, the anterior cardinals and the posteriorcardinals. However in the elasmobranchs only one hepaticveinleads intoit.

- **Atrium.**Fromthesinusvenosusthebloodflowsintotheatrium. The atrium is the largest of the chambers and weaklymuscular. It pushes the blood, with weak contractions in theventricle.

- **Ventricle**. The ventricle is the only well-muscled chamber,nearly as large as the atrium it is the work horse of the heart,itscontractionsdrivethebloodaround thebody.

- **Conus or Bulbusarteriosus**

The last chamber of the fish heart is called the bulbusarteriosus in the teleosts, but the cornusarteriosus in theelasmobranchs.Thedifferencebetweenthesechambersis that the cornusarteriosus of sharks and rays containsmanyvalveswhilethebulbusarteriosusofbonyfishcontainsnone.Botharealikeinbeingpri marilyelasticand work to reduce the pulsed nature of the blood leavingtheventriclegivingitamoreeven,constant flow.

The heart of fishes is known as branchial heart, because its main function is to **pump venous blood to ventral aorta into gills (branchial) and then to somatic vasculature**. Thus branchial and systemic vascular beds are arranged in series with heart.

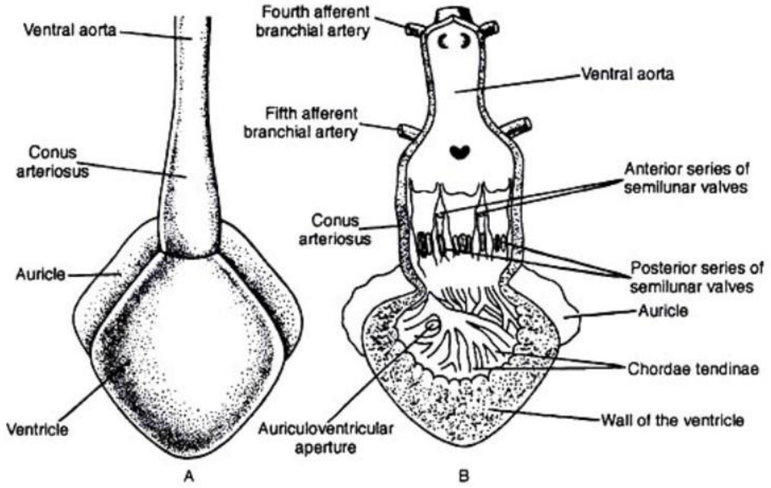


Fig. Heart of Shark(*Scoliodon*): A. Heart showing the position of different chambers. B. Longitudinal sectional view of heart shoing the internal structure.

Fig.6.3.1A and B: Heart of Shark

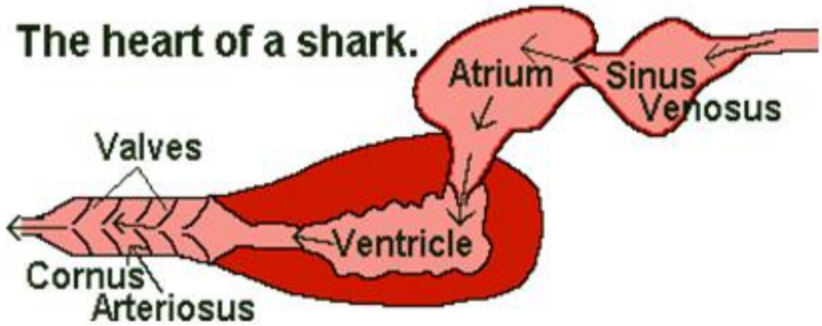


Fig.6.3.2: Heart of Shark

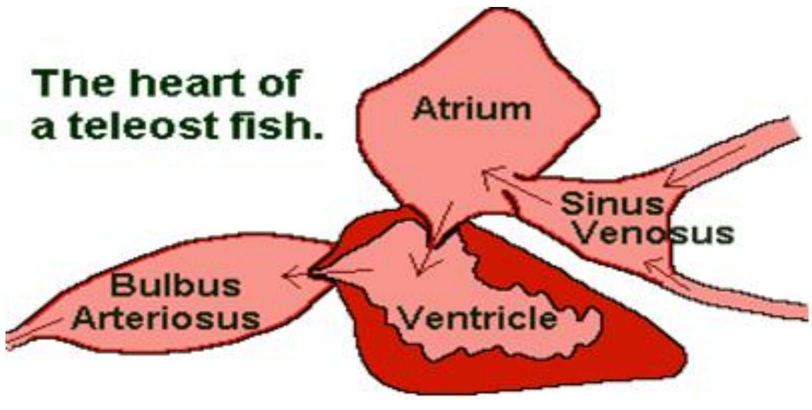


Fig.6.3.3: Heart of teleost fish

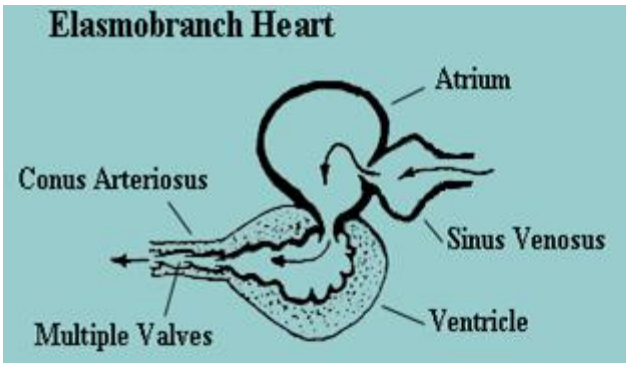


Fig.6.3.4: Elasmobranch Heart

Heart in other Teleosts: The heart of cyprinids like *Labeorohita, Cirrhinamrigala, Catlacatla* and *Schizothorax* are unique in structure, and very similar to *Tortor*. The heart lies within the pericardial sac anterior to the septum transversum and consists of sinusvenosus, auricle, ventricle, and the bulbusarteriosus. The sinus is a fairly spacious chamber with smooth walls and receives blood through the paired ducticuvieri, paired hepatic veins, a posterior cardinal and an inferior jugular vein. The openings of these blood vessels are not guarded by valves. The sinus opens into the auricle through a sinuauricular aperture guarded by a pair of membranos semi-lunar valves, each having a longer limb that projects anteriorly into the auricle.

The auricle covers the ventricle in dorsal view and is fairly large in size with an irregular outline. It is orange in colour, spongy in texture and has a narrow lumen extending upto the ventricle. The spongy wall of the auricle shows numeros spaces or cavities delimited on all the sides by muscular strands running in various directions. The valves of nearly equal size. Each of these valves has shorter limb attached to the wall of the auricle and a longer one adhering to the ventricular wall, while the convexities of the valves project into the auricle.

The ventricle is a highly muscular chamber with thick walls and a narrow lumen in between. The ventricle leads into the bulbusarteriosus through the ventriculo-bulbus opening guarded by a pair of semi-lunar valves. Each valve has a shorter limb attached to the wall of the ventricle and a longer one connected to the wall of the bulbus in such a way as to cross the limb of the other valve. The valves hang into the lumen of the ventricle. There are no conus, and the base of the ventral aorta is thickened to form the bulbus. The bulbus has thick walls and a narrow lumen. Its cavity has a number of thin ribbon-like trabeculae running parallel to each other. The bulbus extends anteriorly into the ventral aorta.

In *Clariasbatrachus*, *Mystusaor* and *Wallagoattu*, the sinus venosus is a thin walled chamber with a pair of membranous sino-auricular valves are absent in it. The sinu- auricular aperure is guarded by five to seven nodular valves in *Notopterusnotopterus* and eight to ten in *N.chitala*, four auriculo-ventricular valves are present, of which two are smell in size. A muscular conusarteriosus is present between the ventricle and the bulbus in *N. chitala*. The ventriculo-bulbar valves are also peculiar in being ribbon like and form a pair of vertical partitions dividing the cavity of the bulbus into three chambers in *Notopterus.*

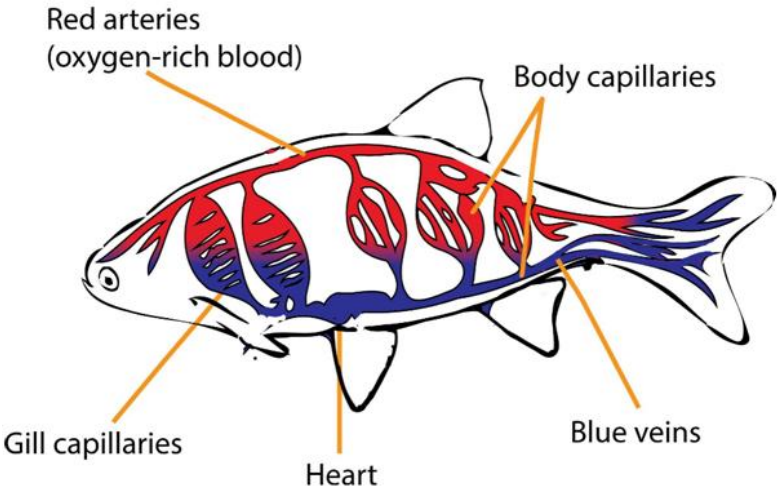


Fig.6.3.5: Two chambered heart of Fish

6.4 Principal blood vessels and circulation of blood (Elasmobranchs, Teleost and Dipnoi)

- **Blood vessels:**

The blood vessels comprise the arteries, veins and the capillaries.Arteries carry blood away from the heart while the veins carry it towards the heart. On their course both the arteries and veins divide and subdivide into the branches of diameter lesser than the blood vessels of their origin. Thus, the areries divide successively into branches called arterioles and the capillaries. The capillaries of arteries and veins join together and form a closed network of vascular system, that has no direct connection with any other system of the body except with the lymphatic system, with which it is closely proximated.

Aortic arches:

The embryonic blood vessels, developing in conjugation with the visceral arches are called aortic arches. They connect the ventral aorta with he radices of dorsal aorta and are chiefly concerned with the spply of the blood to the respiratory surface. Any modification in the respiratory surfaces affects most prominently the aortic arches, which become adapted bychanging in accordance with the change in respiratory surface.

Fundamentally, the origin and arrangement of aortic arches follow a basic pattern of organization from pisces to higher classes. Typically, the aortic arches originate in pairs from the ventral aorta and connect on either side with the radix of dorsal aorta. Typically six pairs of aortic arches develop, and their number relates with the number of gill pouches present in the fish first pair of ach courses through the mandibular arch, the second through the hyoidean arch and the remaining four through the branchial arches. While passing through various visceral arches, they break up into a network of fine capillaries supplying blood to the gills. Each arch thus has two parts, the one that caries deoxygenated blood to the gills is the afferent branchial part while the other carrying the blood from gills to the radix is the efferent branchial part. Variations in the basic pattern in aortic arches are found within the different groups of fishes.

- **Arterial system:**

Arteries of the fishes may be divided into three groups, viz. the arteries supplying the anterior (head) region, arteries supplying the branchial (gill) region and arteries from the dorsal aorta. The dorsal aorta formed by the union of a pair of radices, extends behind mid dorsally, along the length of the trunk to the caudal region (tail). All along its course, it gives off many somatic and visceral branches. Somatic branches include arteries supplying to fin muscles, epaxial muscles, skin, vertebral column and long parietal vessels encircling te body wall to mid-ventral line. Visceral organs such as liver, pancrease, digestive tract, urinogenital organs etc. The arterial system in various groups of fishes shows almost common pattern.

In the Scoliodon, the ventral aorta rus along the ventral surface of the pharynx and bifurcates into two,each of which divides again to form the first and second afferent arteries. The first afferent vessel supplies blood to the hyoideandemibranch, while the second runs along the first branchial arch and supplies blood to both the anterior and posterior gill filaments. The third, fourth and the fifth afferent arterirs arise from the ventral aorta atalmost equal distance from each other and run along the second, third and the fourth branchial arches to supply blood to the gill filaments. The third and the fourth afferent vessels of each side arise from the ventral aorta by a separate aperture, but the fifth pairs of afferents, have a common opening.

The blood from the gills is collected by a series of nine efferent branchial arteries on each side. Of these the first eight arteries join in pairs to form loops surrounding the first to fourth gill clefts. The loops are connected with each other by short connecting arteries. The posterior artery of each loop is wider than the anterior one. The ninth efferent vessel does not form a loop, and is connected to the fourth loop by a longitudinal connective. Each branchial loop continues into an epibrancial artery, which runs backward and inward towards the mid –dorsal line and join to form the dorsal aorta. The dorsal aorta runs posteriorly along the length of the body to supply oxygenated blood to various organs of the body, and continues as the caudal artery in the tail region.

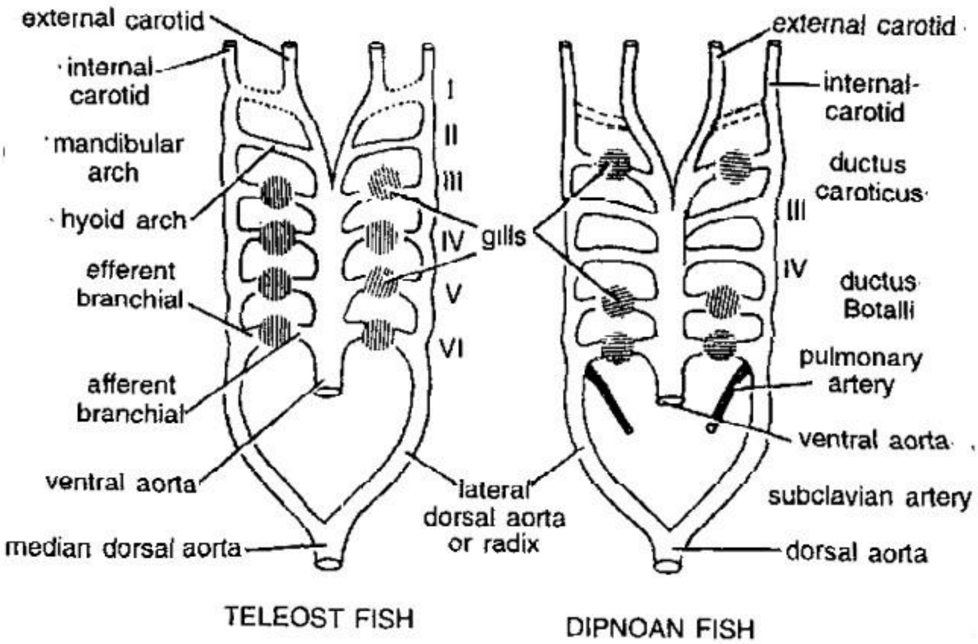


Fig.6.4.1: Arterial system of fish

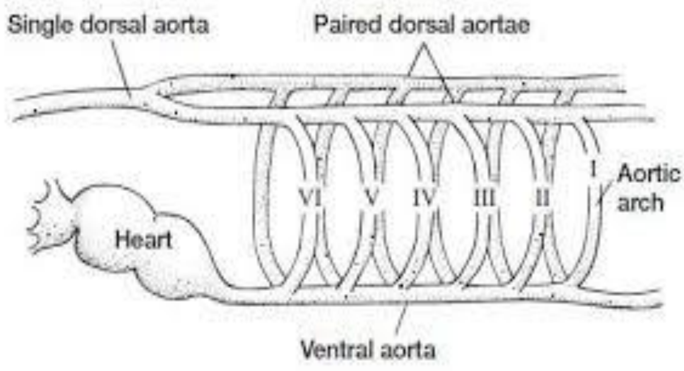


Fig. 6.4.2: Cardiovascular system of fish

AFFERENT AND EFFERENT BRANCHIAL VESSELS IN ELASMOBRANCHES ARTERIAL SYSTEM IN ELASMOBRANCHES

- **Afferent branchial arteries**

The ventral aorta arises from the conusarteriosus and veins forwards along the ventral surface of the pharynx right upto the posterior border of the hyoid arch where it bifurcates into two branches each branch divide into first and second afferent branchial arteries. The first afferent branchial artery runs along the posterior border of the first branchial arch and supplied arterial branches to anterior and posterior gill lamellac of the first branchial arch of the third, fourth and fifth afferent branchial arteries arise from the ventral aorta almost equidistant from one another and runs along the outer border of the second third and fourth branchial arches. This supply the blood to the 3rd 4th and 5th gill arches respectively.

- **Efferent branchial arteries**

The blood from the capillaries of gill lamellac is collected by a serious of blood vessel called the efferent branchial arteries. There are nine efferent branchial vessels on each side (may be less depending upon species) of these the first eight join in pairs to form four complete toops around the 1st four gill clefts. The 9th runs along the anterior border of the fifth gill cleft.
The four loop and 5th efferent branchial arteries are joined by short longitudinal connectives

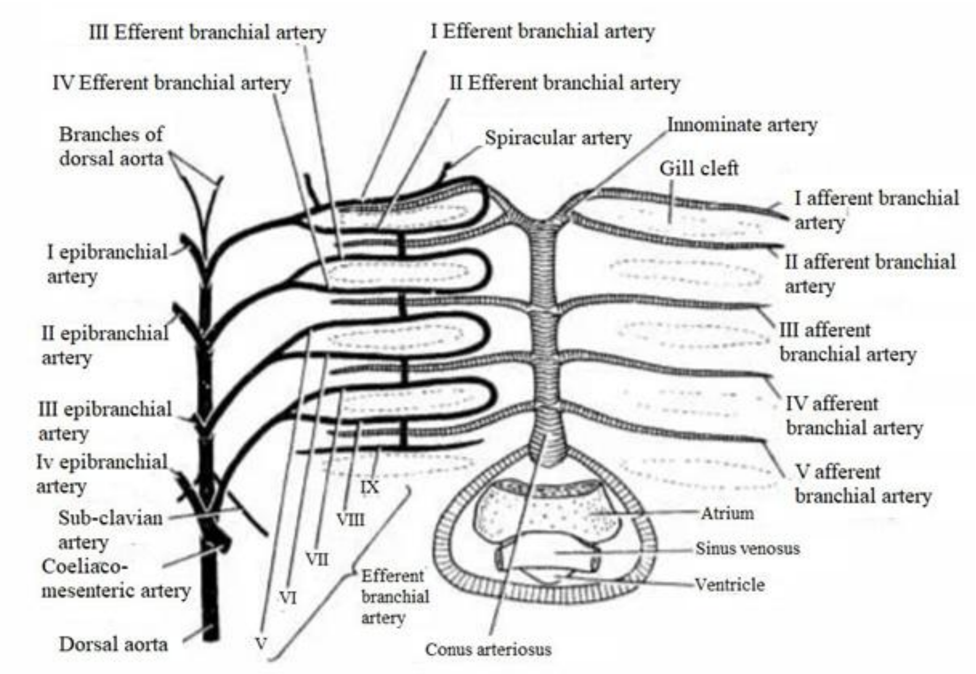


Fig.6.4.3: Showing Afferent and Efferent branchial arteries and their branches in Scoliodon

running across the interbranchial septa. The efferent branchial subsequently join to form the medium dorsal aorta.

- **Arteries of the head**

The first efferent branchial and a small part from the dorsal aorta supply blood to the head. The first efferent branchial vessel gives rise to three branches the external carotid afferent spiracular and hyoidean.

The afferent spiracular runs forward and gives rise to ophthalmic artery. This artery moves forward joins with external carotid to form cerebral artery.

Teleost

Teleosts do not have lymph nodes. The system originates from **vessels with small diameters that generate inter-arterial anastomoses that stem from certain arteries**. Further anastomoses arise from these, forming vessels of larger diameter that run parallel to the main vessels of the primary circulatory system.

Dipnoi

Two efferent branchial arteries from each gill- bearing arch join to form four epibranchial arteries. These four epibranchial arteries of either side join to form a single median dorsal aorta. The pulmonary arteries carry the blood to the lungs. Neoceratodus is peculiar by lacking the second efferent branchial vessel.

- **Afferent and efferent vessels in Teleosts**

In *Tor putitora*, the ventral aorta runs forward and gives off four pairs of afferent branchial arteries. The first pair is formed by the bifurcation of the ventral arota,the second pair has separate origin, but the third and the fourth have a common origin from the ventral aorta. These afferent blood vessels carry venous blood to their respective holobranch and supply blood to the gill filaments and gill lamellae, where the blood is oxygenated. The oxygenated blood is collected by four pairs of efferent branchial arteries, and only one efferent vessel is present in each arch. Of these, the first and the second efferent vessels join to form the

firstepibranchial vessel which runs posteriorly and joins its fellow of the opposite side to form the second epibranchial which also joins the dorsal aorta. The dorsal aorta runs posteriosly, and supplies blood to various organs of the body.

A short common carotid arises from the first efferent branchial vessel and divides almost immediately into an external carotid and an internal carotid artery. Near its base, the carotids receive an efferent pseudobranchial artery from the pseudobranch. A cerebral artery arises from the common carotid to supply the brain. The external carotid artery gives off a number of branches and supplies blood to the opercular and auditory regions and to the muscles of the jaw. The internal carotid artery supplies blood to the snout and the optic region. A small branch of the internal carotid runs towards and middle line and joints its fellow of the opposite side to form the circuluscephalicus.

In different species of teleost the circuluscephalicus is also formed in different ways. In some species circuluscephalicus is formed by the first and second pair of efferent vessels, while in other all the four pairs of efferents join in its formation. A pseudobrnch is present in *Catlacatla* and *Tor tor*, and receives blood from the afferent pseudobranchial artery arising from the first efferent branchial vessel. The blood is drained from it by the efferent pseudobranchial artery, which joins the internal carotid artery. In *Wallagoattu* and *Mystusaor*, a pseudobranch is absent, and the internal carotid artery is swollen at the base to form the carotid labyrinth in these species

Different species of teleosts show variation in the arrangement of afferent and efferent vessels. Generally, the third and the fourth afferent vessels of each side have a common origin from the ventral aorta, as in *Tor putitora, Wallagoattu, Mystusaor, Rita rita, Clariasbatrachus* and *Notopteruschitala.*

In some species as *W.attu, Catlacatla, N. chitala*, the ventral ends of each efferent vessel is forked, which may be considered a primitive feature. In *Clariasbatrachus*, one pair of efferent branchial arteries are present in each gill arch, as in elasmobranches. In *Clarias*, peculiar air breathing arborescent organs are present on the second and fourth pair of gill arches. These organs are supplied

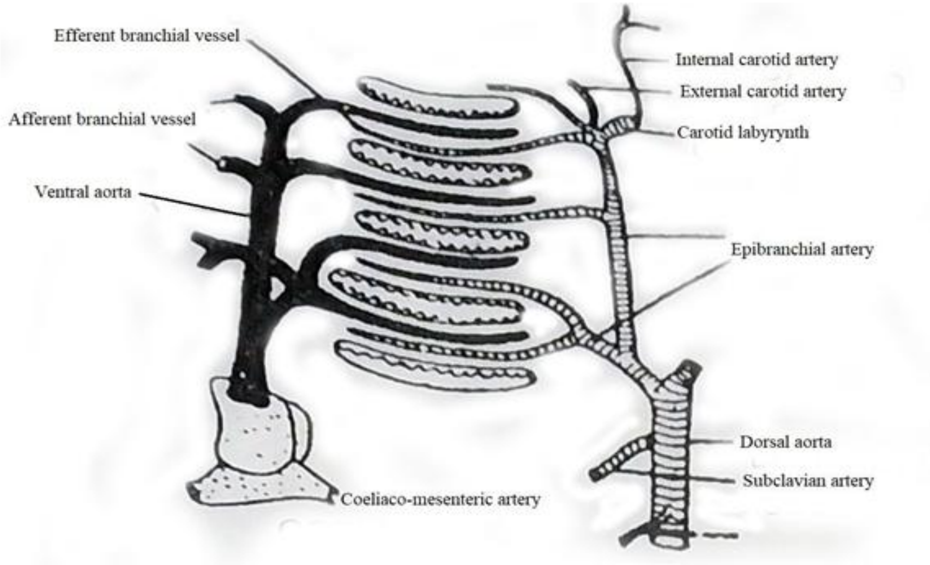


Fig.6.4.4. Arterial and venous system of Teleost

venous blood by a branch arising from the second and the fourth afferent branchial vessels. The oxygenated blood from the arborescent organs is received by the second and fourth efferent arteries of each side.

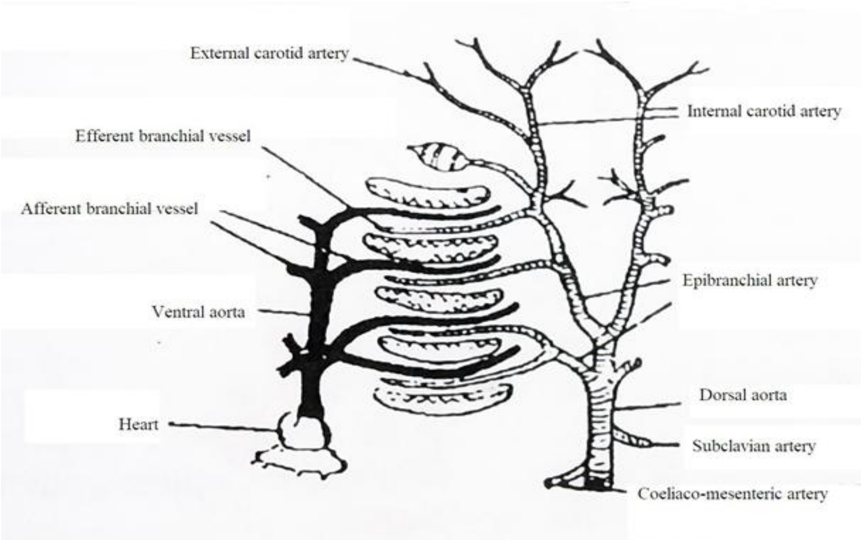


Fig.6.4.5: Showing arrangment of blood vessels in the respiratory region of Tor tor

The circulatory system is well developed. The blood is composed of all the cellular entities observed in higher vertebrates. The introduction of pulmonary respiration in the lung-fishes results in the attainment of much complicacy in the cardiac structure. The heart is enclosed in a stiff pericardium.

Fig.6.9: Showing blood vessels in the respiratory region of *Wallago attu*

The heart lies

enclosed in pericardium behind the gills. The heart of *Protopterus*and *Lepidosiren*is typically built on the same plan, but in Neoceratodus the heart is slightly different. The heartof the lung-fishes consists of four chambers, the sinus venosus, auricle, ventricle and conusarteriosus.

The sinus venosus is incompletely divided into two parts. It opens into the auricle by a broad sinuauricular opening. The auricle becomes dilated on either side of a thin and perforated inter-auricular septum, i.e., the cavity of the auricle is almost divided.

As the septum contains pores, the blood of the two auricular cavities becomes mixed up. The cavity of the right auricle receives venous blood from the sinus venosus while the left cavity gets oxygenated blood from the pulmonary vein. The pulmonary vein from the lungs passes through the sinus venosus. The auricles are communicated with the ventricle by a large auriculoventricularaperture.This aperture is plugged by a large fibrous cushion, called auriculoventricular cushion. It is continued into the ventricular cavity as an incomplete inter-ventricular septum.

Although the ventricle appears to be divided into two parts by the presence of septum, the ventricular cavity is single and lies anterior to the so-called inter-auricular septum. The presence of auriculo-ventricular cushion is peculiar and the auriculoventricular aperture may be opened or closed by raising or lowering the cushion.

The conusarteriosus becomes spirally twisted and the cavity becomes complicated by the presence of valves. A spiral veins is present. It begins ventrally and extends forward to the anterior end of the conus. Three rows of proximal valves are present in the conus of Protopterus and Lepidosiren. But in Neoceratodus the conus lacks the spiral valve and a series of semilunar valves marks the course.

There are a few rows of proximal and two rows of distal valves in the conus of Neoceratodus. The valves in the conus are so arranged that the blood from the right side of the auricle is directed into the last two branchial arches and that

from the left side into the first two. By this way a mechanism towards the separation of systemic and pulmonary circulations is achieved.

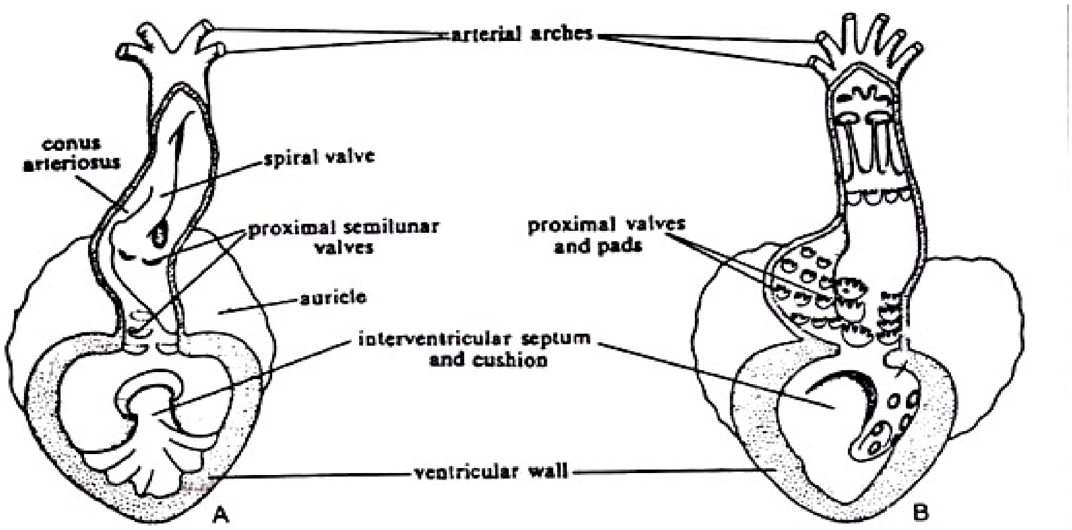


Fig.6.4.6: Diagrammatic sectional (longitudinal) view of the heart- A. Protopterus and B. Neoceratodus (after Jollie,1962).

The lung-fishes possess inconspicuous ventral aorta. The four afferent branchial arteries arise from the anterior end of the conus immediately outside the pericardium (Fig. 6.41). The afferent artery carrying blood to the hyoidean hemi branch originates from the first one.

The arches bearing gills are provided with afferent and efferent branchial branches. Two efferent branchial arteries from each gill- bearing arch join to form four epibranchial arteries. These four epibranchial arteries of either side join to form a single median dorsal aorta.

The pulmonary arteries carry the blood to the lungs. Neoceratodus is peculiar by lacking the second efferent branchial vessel. In all the lung-fishes, a coronary artery is present which arises from the anterior efferent branchial arches.

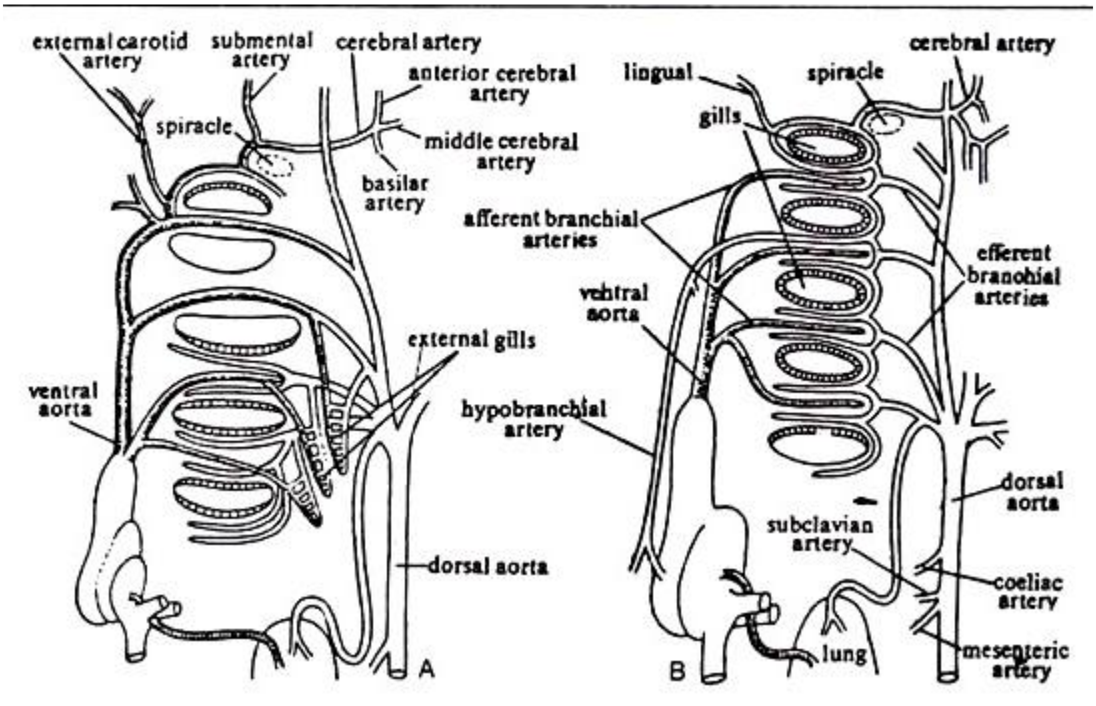


Fig.6.4.7: Schematic diagram of the anterior part of the aortic arches and their branching in A. Protopterus and B, Neoceratodus(afterJollie, 1962)

The venous system presents certain advanced features which are not observed in other fishes (Fig. 6.42). The blood from the anterior part of the body is returned to the heart by two Percivals or ductusCuvieri. Each precaval is formed of an inferior jugular, anterior cardinal and subclavian veins. But the left precaval, in addition to the three veins, receives the posterior cardinal vein.

The posterior parts of both the posterior cardinal veins constitute the renal portal veins and are connected by interconnecting cross-channels. Presence of an inferior vena cava is a characteristic feature in the venous system of lung- fishes. This vessel collects majority of the blood from the posterior part of the body and conveys it directly to the sinus venosus.

The inferior vena cava enters into the liver and also receives the hepatic veins. The hepatic portal drains the intestine by the sub-intestinal and infra intestinal veins. Both the inferior vena cava and the left posterior cardinal vein have been formed by the renal veinsdraining blood from the kidneys. Both these veins receive segmental and genital veins on their way to the heart.

The blood from the tail region is carried by a caudal vein which is bifurcated into two renal portal veins. The renal portal veins break up into capillaries inside the kidneys. In Neoceratodus, the caudal vein opens into the inferior vena cava and not into the renal portal veins as seen in other two genera.

In Neoceratodus, the renal portal vein is connected by a ventral abdominal vein and the caudal vein by the lateral cutaneous veins. The pulmonary veins carrying blood from the lungs unite to form a common pulmonary vain and opens into the left auricle. The venous system presents many peculiarities and the posterior portion shows an intermediate stage between that of Elasmobranchs and Amphibia.

Fishes are cold-blooded aquatic vertebrates and can be found in both saline and fresh water. Fish have a single circuit for blood flow and a two chambered heart that has only a single atrium and a single ventricle. The circulatory system of fishes is responsible for transporting

blood and nutrients throughout the body. It has a closed circulatory system, i.e. blood travels across the body through the network of blood vessels. Fish heart carry only deoxygenated blood that is why it is called as venous heart. Fish have a closed circulatory system with a heart that pumps blood around the body in a single loop-from the heart to the gills, from the gills to the rest of the body, and then back to the heart, this is called gill circulation.

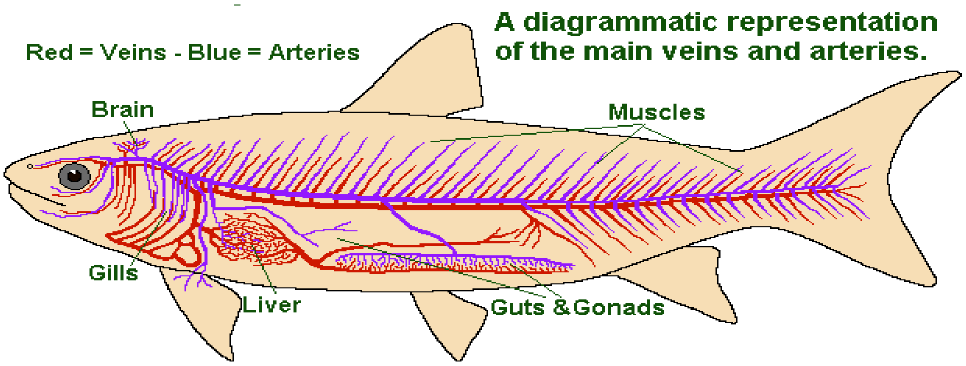


Fig.6.4.8:Circulation of blood

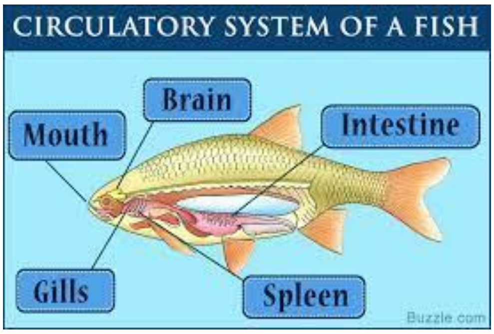


Fig 6.4.9:circulatory system of fish

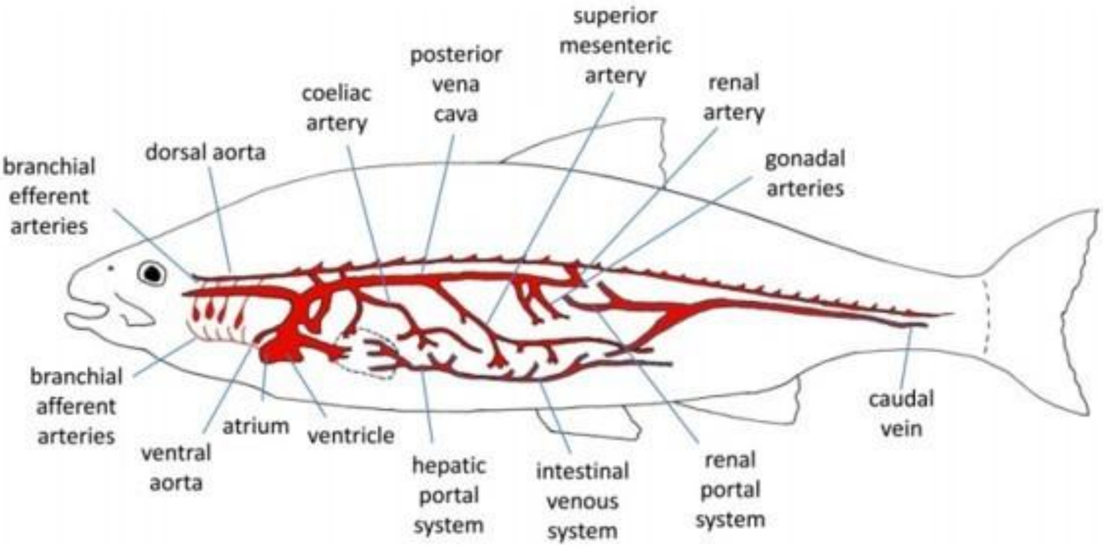


Fig6.4.10: Circulatory system of teleost fish

- **Circulatory System of Dipnoi:**

The circulatory system is well developed. The blood is composed of all the cellular entities observed in higher vertebrates. The introduction of pulmonary respiration in the lung-fishes results in the attainment of much complicacy in the cardiac structure. The heart is enclosed in a stiff pericardium.

The heart is situated somewhat posterior to the gills. The heart of Protopterus and Lepidosiren is typically built on the same plan, but in Neoceratodus the heart is slightly different . The heart of the lung-fishes consists of four chambers, the sinus venosus, auricle, ventricle and conusarteriosus.

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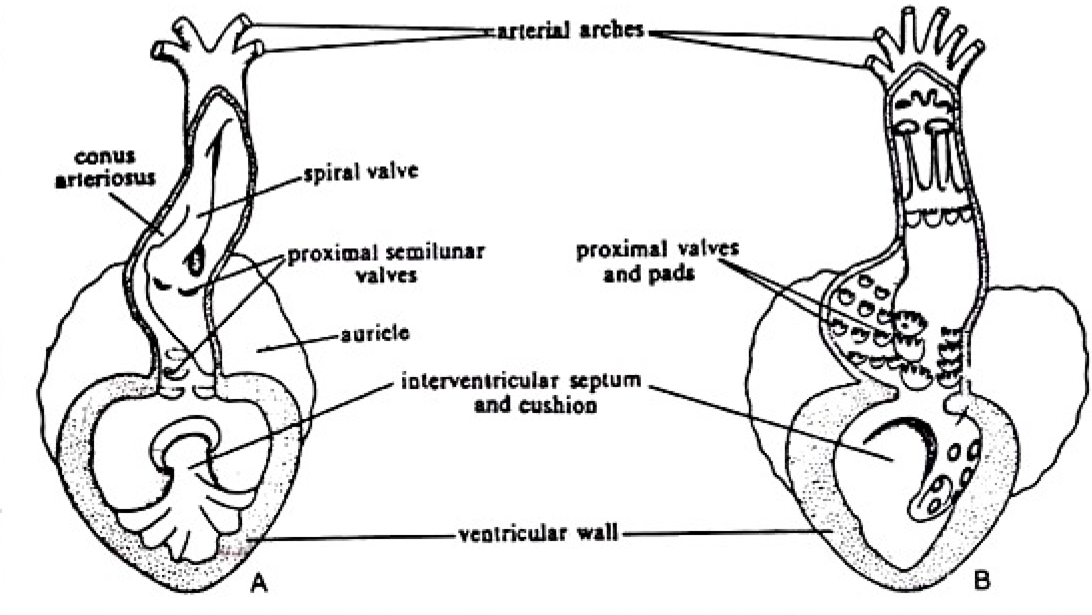

Fig.6.4.11: Diagrammatic sectional (longitudnal)view of the heart A. Protopterus and B.Neoceratodus

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The inferior vena cava enters into the liver and also receives the hepatic veins. The hepatic portal drains the intestine by the sub-intestinal and infra intestinal veins. Both the inferior vena cava and the left posterior cardinal vein have been formed by the renal veins draining blood from the kidneys. Both these veins receive segmental and genital veins on their way to the heart.

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- **Working of the heart:**

The venous blood flowing continuously towards the heart reaches the sinus and passes into the auricle by pushing apart the semilunar valves. During this, the pockets of the valves also become full of blood and the pressure due to the contraction of the auricle causes the valves to swell and adhere with each other, thus preventing the backward flow of the blood. The blood now flows from the auricle into the ventricle by pushing apart the four auriculo-ventricular valves. As soon as the ventricular cavity is full, the valves also receive the blood, so that they bulge out and adhere with each other so as to effectively close the opening and thus, prevent the backward flow of the blood. The blood, now, pushes aside the ventriculo bulbar valves, to enter the bulbus. Here again, the increased pressure insidethebulbus causes the valves to swell and close the passage**,** preventing backward flow of the blood, which passes forward into the ventral aorta.

Fish have a very low pressure circulatory system. There is very little blood pressure in the venous system and return to the heart is aided in all species by skeletal muscular contraction and in some species by **accessory hearts**. By the time the blood reaches the sinus venosus, pressure is essentially zero. Contractions of the atrium draw the blood from the sinus venosus and help fill the ventricle. Ventricular contractions generate the pressure to move the blood through the body.The bulbous arteriosus is neither contractile nor valved, but elastic. It expands with each ventricular contraction as it fills with blood and maintains aortal pressure during ventricular diastole. In terms of pressure, the gills are somewhat restrictive, with blood cells meeting resistance within the lamellae. When the ventricle contracts, it sends a charge of blood into the bulbous, when the ventricle expands, the valve between the bulbous and the ventricle keeps the blood from going back into the ventricle. Coupled with the resistance of the gills, this causes the elastic bulbous to expand, and then as the blood continues to flow through the gills the bulbous begins to "deflate", then comes another charge of blood from the ventricle. The bulbous functions to average out the pressure extremes and keep a steadier flow of blood going through the gills.

If teleosts did not have a bulbous, then the blood would strongly pulse over the gills. It appears to be adaptive for the fish to move the blood across the gills at a more constant rate. However, there is some pulsing even with the bulbous, and fish actually synchronize their heartbeat with their opercal movements in order to match peak blood flow with the water pulses associated with the buccal pump. This is especially evident when fish are subjected to hypoxia.

6.5 HEMODYNAMICS:

Hemodynamics is the forces which circulate blood through the body. Specifically Hemodynamic is the term used to describe the intravascular pressure and flow that occurs when the heart muscle contracts and pumps blood throughout the body.

"Haemodynamics" refers to "the physical study of flowing blood and all the solid structures(such as arteries) through which it flows" The factors influencing hemodynamics are extensive and include circulating fluid volume, respiration, vascular diameter and resistance, and blood viscosity.

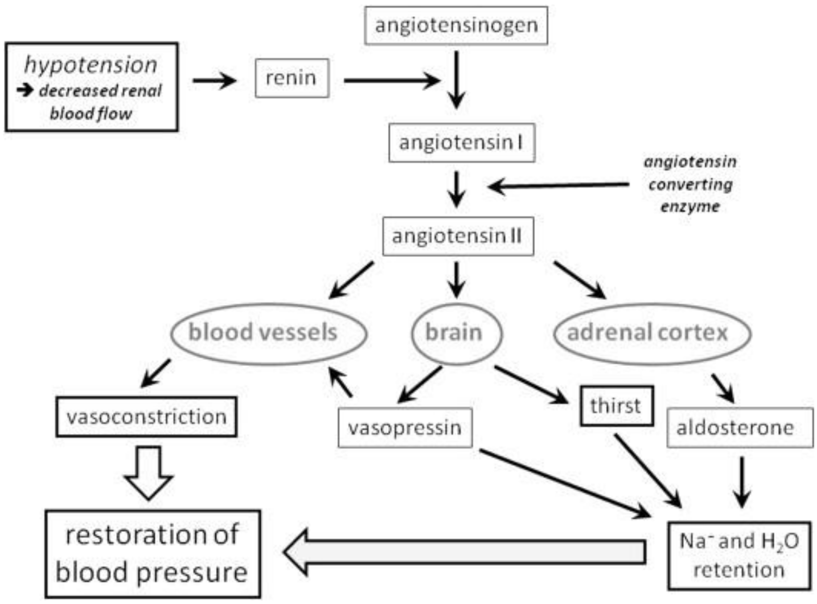


Fig. 6.5.1: Physiology of hemodynamic homeostasis

Homeostasis of hemodynamics refers to the regulation of the blood circulation to meet the demands of the different organ and tissue systems. This homeostasis involves an intimate interaction between peripheral metabolic needs, vascular adaptations to meet these needs and cardiac adaptation to provide the driving force to circulate the blood.

6.6 CARDIAC OUTPUT

"Cardiac output refers to the volume of blood pumped out per ventricle per minute."

Cardiac output is the function of heart rate and stroke volume. The amount of blood pumped by the left ventricle in one compression is called the stroke volume.

Cardiac output is defined as amount of blood pumped out of each ventricle per minute.cardiac output is expressed in two forms.

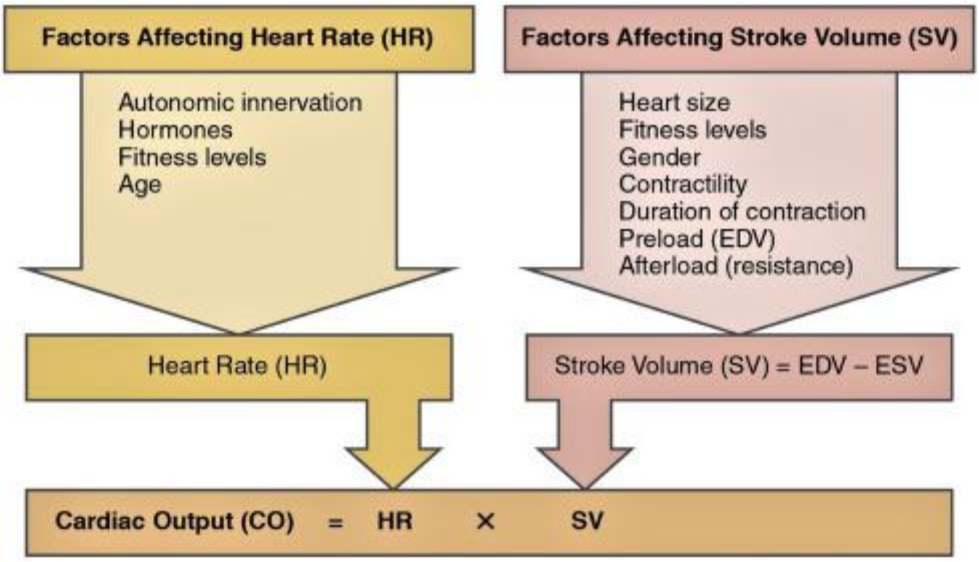
1. Stroke volume
2. Minute volume

   Cardiac output varies widely with the level of activity of the body

   Unit – liter (ml) / min.

CO (cardiac output rate) =SV **(stroke volume)** X HR**(heart rate)**		
(ml\minute)	(ml\beat)	(beats\minute)

The fish heart can dramatically increase cardiac output by modulating stroke volume,relying less on increasing heart rate. Fish hearts can therefore be distinguished from mammalian hearts by being capable of considerbly larger changes in stroke volume.The stroke output varies with the size of the individual. Smaller individuals of a species, although possessing a smaller absolute output, have a larger output in relation to their size than do larger individuals.Over the size range at which they can be compared (300 to 600 gm.)



Factors Effecting Cardiac Output

- Heart Rate
- Force of contraction of heart
- Blood volume
- Venous return

6.7 CIRCULATION TIME

Fish have a single circuit for blood flow and a two-chambered heart that has only a single atrium and a single ventricle. The atrium collects blood that has returned from the body and the ventricle pumps the blood to the gills where gas exchange occurs and the blood is re-oxygenated; this is called gill circulation.

Or

Blood returns to the heart via a vein. Because blood only passes through the heart once in a complete circuit around the body, fishes are said to have a single circulation. **Only venous blood flows through the heart in fishes**. So it is known as venous circulation.

One disadvantage is that the narrow gill capillaries slow blood flow, resulting in low blood pressure in the body.

The average circulation time in **3 min (46 ml kg-1/35 ml min-1 kg-1) in yellowtail (Seriolaquinqueradiata) and 1.9 min (35 ml kg-1/18 ml min-1 kg-1) in rainbow trout (Oncorhynchusmykiss)**.

In air-breathing vertebrates, high metabolic rates are necessarily correlated with short circulation times.The total circulation time with one pump is equal to total active circulating volume divided by pump output. The total circulation time with one pump is equal to total active circulating volume divided by pump output

- **Blood cells of fishes**

The blood in fishes is red in color and consists of fluid plasma and blood cells. Red Blood cells, White Blood Cells and Thrombocytes are present in plasma RBC (erythrocytes) are nucleated, oval and contain haemoglobin The WBCs may be grannular or agranular. They are called basophils, acidophils, neutrophils, monocytes and lymphocytes Thrombocytes (responsible for blood coagulation.

¬ Blood clotting is initiated when platelets and damaged tissue secrete clotting factor called prothrombin activator ¬ Prothrombin activator and calcium ions catalyze the conversion of prothrombin to thrombin which then catalyzes the conversion of fibrinogen to fibrin threads. ¬ Fibrin threads are sticky and trap more platelets, further sealing the leak.

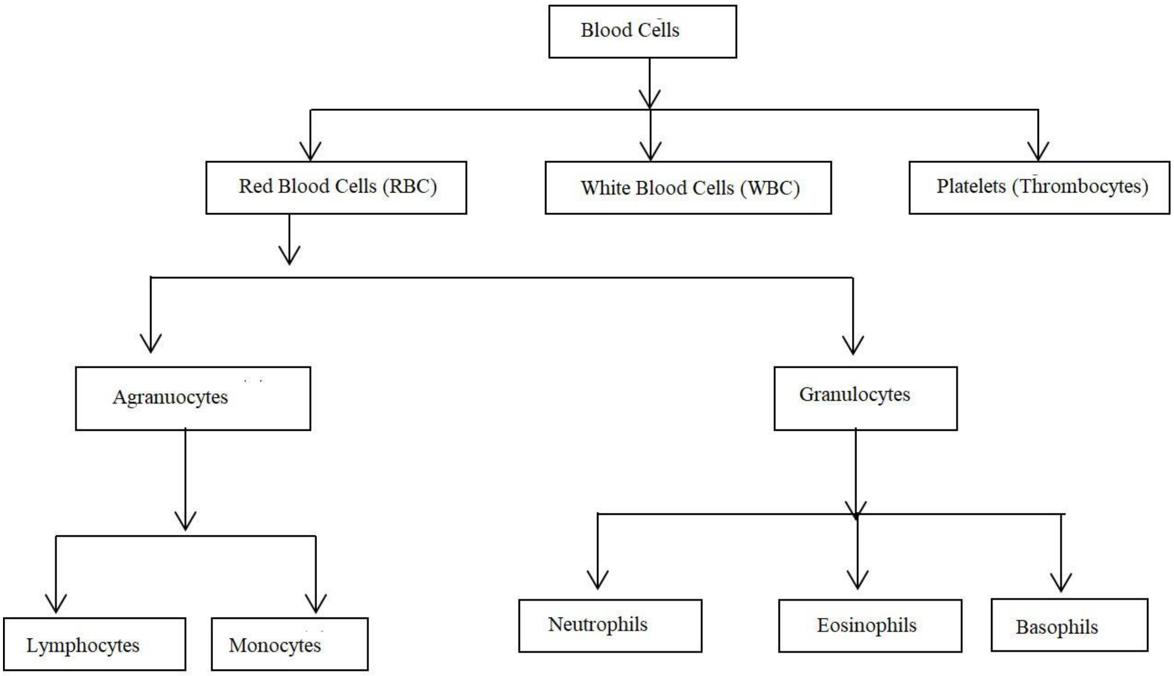


Fig.6.7.1: Blood circulatory system of fish

6.8 FISH HAEMOGLOBIN:

Haemoglobin is the respiratory pigment in most of the fishes and its amount varies with the total number of erythrocytes in the fish.

However, there is no haemoglobin in the Antarctic Ice fishes, which survive without haemoglobin in blood, because:

i. Their metabolic oxygen requirement is low, and the cold Antarctic water has a high level of dissolved oxygen.
ii. These fish are very sluggish.
iii. They have special adaptations,such as the large heart and blood volume which help in efficient moment of their blood.

Thus, these fishs are able and can get along without haemoglobin. Fish haemoglobin is basically of two types: monomeric and tetrameric. Hemoglobin is composed by polypeptide chains, known as globins, each having a prosthetic group called heme, identical in every fish species. On the other hand, globins differ from species to species and among isoforms. Remarkably, globins seem to occur in all organisms and tissues, exhibiting a diversity of quaternary structures and a large number of functions apart from oxygen transportation and storage, as illustrated by cytoglobins and neuroglobins In teleosts, including the Atlantic salmon, carp and zebrafish, the adult alpha globin gene is adjacently linked to the beta globin gene and the embryonaryglobins are completely different from adult globins. In vertebrates, the hemoglobin molecule includes four globin chains that create a stable tetramer formed by two alpha-like and two beta-like chains with 141 and 146 amino acid residues, respectively. Each one contains a heme group, which allows the binding of four oxygen (O2) molecules in a reversible form, according to the scheme below:

Hb + 4O2 = Hb(O2)4

deoxy-Hb oxy-Hb

The main function of hemoglobin is to transport oxygen from the gas-exchange organs to peripheral tissues. It must be able to bind oxygen strongly but at the same time to release it when necessary, depending on the partial pressure of the gas . Reversible oxygen binding is possible thanks to the heme group, specifically with the participation of an iron atom in the ferrous form, Fe2+. For some species of primitive fish such as lampreys and hagfish, reversible hemoglobin dissociation occurs in response to oxygen binding. In the case of lampreys, the oxygenated form is monomeric, undergoing associations with dimers and tetramers when deoxygenating. In Myxineglutinosa (hagfish) there are three monomeric hemoglobins in the oxygenated form, but when they release O2, there is an association to form heterodimers and heterotetramers.

Hemoglobins are particularly important in fish adaptation as they constitute an interface between the organism and the environment. Fish particularly face a very variable environment and temporal and spatial alterations in oxygen availability, in contrast to terrestrial animals. However, a variety of environmental and physiological adjustments are observed in fish exposed to environmental hypoxia in order to improve O2 transfer. Many Amazonian fish obtain O2 directly from the air when submitted to hypoxia, being obligate or facultative air breathers. The anatomical modifications that allow accessory air-breathing include changes in the gills, mouth, stomach, intestine, and vascularization of the swim bladder. Species that do not have this capacity are obliged to accomplish metabolic and behavioral changes to deal with limited O2 availability. Such adjustments involve ventilation frequency and volume, heart rate, increase in the number of erythrocytes, hematocrit and hemoglobin concentrations, changes in organic phosphate concentrations, presence of iso-hemoglobins with different functional properties, and metabolic depression .

The monomeric haemoglobin is characteristic of the Agantha (lampreys and hag fishes), and consists of a single polypeptide molecule with a molecular weight of about 17,000 daltons. Tetrameric haemoglobin is found in most higher fishes. It is composed of four chains of amino acids (two alpha and two beta chains), with the molecular weight of about 65,000 daltons. The tetrameric haemoglobins are also of many kinds, and more than one may be found in one fish. For example, rainbow trout has four kinds of haemoglobins in its blood, the gold fish has three kinds, and the Americn eel, Anguilarostrata, has only two kinds of haemoglobin in its blood. Each type of haemoglobin has a different functional property, so that various combinations have been evolved in response to different environmental conditions.

In migratory fishes, as in the catadromus eel, one kind of haemoglobin has a high oxygen affinity in salt water, while the other type has a high oxygen affinity in fresh water. The presence of polymorphic haemoglobin is therefore, considered an adaptation to acclimatise the eels in the environments of different salinity, and the fish is able to maintain an approximately constant amount of blood oxygen.

It has been reported that goldfish, acclimatised to 2 C had two different haemoglobins, while those at 20-35C had three types. It has also been shown that the third type can be made to appear and disappear with temperature changes within a few hours. Possibly, the third haemoglobin is not synthesized fresh, and is the result of rearrangement of alpha and beta subunits in other haemoglobins.

Several factors such as the pH, temperature, CO_2concentration, and organic phosphate concentration, influence the blood oxygen affinity. Of these, pH and CO2 concentration in blood are the most important factors. A decrease in affinity for oxygen, with decreasing pH or increasing Pco2 (Bohr effect) normally serves to "drive off" oxygen from the haemoglobin, thereby raising plasma Po2 and facilitating its diffusion to surrounding tissues.

6.9 SUMMARY

Fishes are cold-blooded aquatic vertebrates and can be found in both saline and fresh water. The circulatory system of fishes is responsible for transporting blood and nutrients throughout the body. It has a closed circulatory system, i.e. blood travels across the body through the network of blood vessels. Fish heart carry only deoxygenated blood that is why it is called as Venous heart.

There are 3 basic type of heart found in animals: a 2 chambered heart, a 3 chambered heart, and a 4 chambered heart. Fish have 2 chambers, one atrium and one ventricle. Amphibians and reptiles have 3 chambers: 2 atria and a ventricle. Crocodiles are the one reptilian exception, as they have 4 chambers (2 atria, 2 ventricles). Birds and mammals have 4 chambers (2 atria and 2 ventricles).

The circulatory, or blood vascular, system consists of the heart, the arteries, the capillaries, and the veins. It is in the capillaries that the interchange of oxygen, carbon dioxide, nutrients, and other substances such as hormones and waste products takes place. The capillaries lead to the veins, which return the venous blood with its waste products to the heart, kidneys, and gills. There are two kinds of capillary beds: those in the gills and those in the rest of the body. The heart, a folded continuous muscular tube with three or four saclike enlargements, undergoes rhythmic contractions and receives venous blood in a sinus venosus. It passes the blood to an auricle and then into a thick muscular pump, the ventricle. From the ventricle the blood goes to a bulbous structure at the base of a ventral aorta just below the gills. The blood passes to the afferent (receiving) arteries of the gill arches and then to the gill capillaries. There waste gases are given off to the environment, and oxygen is absorbed. The oxygenated blood enters efferent (exuant) arteries of the gill arches and then flows into the dorsal aorta. From there blood is distributed to the tissues and organs of the body. One-way valves prevent backflow. The circulation of fishes thus differs from that of the reptiles, birds, and mammals in that oxygenated blood is not returned to the heart prior to distribution to the other parts of the body.

In lungfish, there is a pulmonary vascular circuit. Blood returning from the body flows into the sinus venosus and then into a divided atrium. Blood returning from a separate circuit to the lung flows into the other side of the atrium. The ventricle is partially divided and only partial mixing of the oxygenated and unoxygenated blood occurs. A special bulbous further maintains this separation, sending the oxygenated blood into tissue circulation and unoxygenated blood to the gills. The **pulmonary** artery takes off of one of the efferent branchial arteries, sending the blood to the lung and then the pulmonary vein takes it back to the heart. Lampreys have an unusual circulatory trait that is unique among vertebrates: the artery that feeds the gut runs inside the vein that drains the gut. Also, lampreys lack a hepatic portal system.

The blood in fishes is red in color and consists of fluid plasma and blood cells. Red Blood cells, White Blood Cells and Thrombocytes are present in plasma RBC (erythrocytes) are nucleated, oval and contain haemoglobin The WBCs may be grannular or agranular. They are called basophils, acidophils, neutrophils, monocytes and lymphocytes Thrombocytes (responsible for blood coagulation)

Details of Blood Clot Formation: Blood clotting is initiated when platelets and damaged tissue secrete clotting factor called prothrombin activator. Prothrombin activator and calcium ions catalyze the conversion of prothrombin to thrombin which then catalyzes the conversion of fibrinogen to fibrin threads. Fibrin threads are sticky and trap more platelets, further sealing the leak.

Circulatory system in Prawn In prawn-circulatory system is open or lacunar type, in which the veins and capillaries are totally absent. The blood vessels open into spaces. These spaces are without a proper epithelial lining and are called lacunae or sinuses. The sinuses together form the body cavity which looks like a coelom but filled with blood and devoid of epithelial lining is known as haemocoel Circulatory system in Palaemon consist of

1. Pericardium
2. Heart
3. Arteries
4. Blood Sinuses
5. Blood Channels

6. Blood

Vertebrate hemoglobin, contained in erythrocytes, is a globular protein with a quaternary structure composed of 4 globin chains (2 alpha and 2 beta) and a prosthetic group named heme bound to each one. Having myoglobin as an ancestor, hemoglobin acquired the capacity to respond to chemical stimuli that modulate its function according to tissue requirements for oxygen. Fish are generally submitted to spatial and temporal O2 variations and have developed anatomical, physiological and biochemical strategies to adapt to the changing environmental gas availability. Structurally, most fish hemoglobins are tetrameric; however, those from some species such as lamprey and hagfish dissociate, being monomeric when oxygenated and oligomeric when deoxygenated.

In **elasmobranchs**, agnathans, and **holosteans**, the fourth chamber, termed conusarteriosus, is not elastic, but fairly rigid, and its wall contains a series of valves to prevent back flow of blood. Since the conus is a more primitive condition, we can think of teleosts having the conus reduced to one valve (between bulbous arteriosus and ventricle) with the bulbous arteriosus evolved from the ventral aorta. In lungfish and amphibians, there is a septum dividing the atrium into two chambers, but not the ventricle.

6.10 TERMINAL QUESTIONS AND ANSWERS

1. Which of the following statements about the circulatory system is false?

   A. Blood in the pulmonary vein is deoxygenated.
   B. Blood in the inferior vena cava is deoxygenated.
   C. Blood in the pulmonary artery is deoxygenated.
   D. Blood in the aorta is oxygenated.

2. Which of the following statements about the heart is false?

A. The mitral valve separates the left ventricle from the left atrium.

B. Blood travels through the bicuspid valve to the left atrium.

C. Both the aortic and the pulmonary valves are semilunar valves.

D. The mitral valve is an atrioventricular valve.

3. Why is blood pressure low in fish?

4. Why are open circulatory systems advantageous to some animals?

   A. They use less metabolic energy.
   B. They help the animal move faster.
   C. They do not need a heart.
   D. They help large insects develop.

5. Some animals use diffusion instead of a circulatory system. Examples include:

   A. birds and jellyfish
   B. flatworms and arthropods
   C. mollusks and jellyfish
   D. None of the above

6. Blood flow that is directed through the lungs and back to the heart is called ________.

   A. unidirectional circulation
   B. gill circulation
   C. pulmonary circulation
   D. pulmocutaneous circulation

7. What is the role of hemoglobin in the fish respiratory system?

8. Why do fish have low blood pressure?

9. How is fish blood oxygenated?

10. How does hemoglobin work in fish gills?

11. How does this fish get enough oxygen without hemoglobin?

12. What type of iron is in fish?

13. What is the main function of the blood vessels in circulatory system?

14. Why is blood circulation in fish called single circulation?

15. What type of blood flow occurs in fish?

Answers

1. C
2. B
3. The fish kidney, unlike the mammalian kidney which is entirely supplied by the arterial system, is largely fed from the venous system. So, **fish blood must always pass through two, and sometimes more, high resistance areas during circulation**. The consequence is relatively low blood pressure compared to mammals.
4. A
5. D
6. C
7. The main function of hemoglobin is to **transport oxygen from the gas-exchange organs to peripheral tissues**.
8. The fish kidney, unlike the mammalian kidney which is entirely supplied by the arterial system, is largely fed from the venous system. So, **fish blood must always pass through two, and sometimes more, high resistance areas during circulation**. The consequence is relatively low blood pressure compared to mammals.
9. As the fish opens its mouth, water runs over the gills, and **blood in the capillaries picks up oxygen that's dissolved in the water**. Then the blood moves through the fish's body to deliver the oxygen, just like in humans.
10. The oxygen can then attach to hemoglobin, **a protein in red blood cells that distributes oxygen throughout the body**. When the oxygen moves throughout the fish's body, it can then diffuse into areas that have too much carbon dioxide. This carbon dioxide will then be carried out of the bodies through the gills.
11. Icefish compensate for their lack of hemoglobin with a variety of other adaptations, including **a large heart, wide blood vessels, large gills, and no scales**. These adaptations increase their blood flow and the amount of oxygen that diffuses into their blood.
12. **Heme iron** is found in meat, fish and poultry. It is the form of iron that is most readily absorbed by human body. You absorb up to 30 percent of the heme iron that you consume.

13. The function of blood vessels is **to deliver blood to the organs and tissues in your body**. The blood supplies them with the oxygen and nutrients they need to function. Blood vessels also carry waste products and carbon dioxide away from your organs and tissues.
14. In single circulation, **the blood passes through a single circuit – where blood is pumped by the heart to the gills for oxygenation, after which the blood flows to the rest of the body and back to the heart**. Animals such as fish are known to have single circulatory systems.
15. Fish have a single circuit for blood flow and a two-chambered heart that has only a single atrium and a single ventricle. The atrium collects blood that has returned from the body and the ventricle pumps the blood to the gills where gas exchange occurs and the blood is re-oxygenated; this is called **gill circulation**.

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UNIT 7: RESPIRATORY SYSTEM

Content

7.1 *OBJECTIVES*

After studying this unit the learner will learn about

1) Gills and aquatic respiration

2) Organization of gills

3) Mechanisms of respiration

4) Structure of a typical Teleostean gill

5) Gill surface area

6) Counter current principle

7) Water flow across the gills

8) Gas exchange

9) Air-breathing fishes: causative factors and structural adaptations

7.2 *INTRODUCTION*

The respiratory process is the process of gaseous exchange between environment and the organism. The gases exchange between the environment and respiratory organs of organisms is termed as external respiration and the gases exchange between blood and the cells of the organism is termed as internal respiration. In this process the O_2 is exchanged with the CO_2 release in the body by the oxidation of food. The O2 is necessary for the oxidation to food to generate energy for organisms. The main purpose of the respiratory system is to obtain oxygen for the metabolism in the organisms to provide energy and to eliminate byproducts (e.g. CO2). This process is different in terrestrial and aquatic animals. In terrestrial animals the exchange of gases (O2 and CO2) occurs between the atmosphere and the lungs. But in the aquatic animal the exchange of gases occurs between gills (respiratory organ) and water. The fishes live in water bodies which can be fresh water systems or saline water systems. So, osmoregulation is also a very important part of fish life. Apart from gills, fishes also have Accessory respiratory organs.

7.3 *GILLS AND AQUATIC RESPIRATION*

In the atmosphere the oxygen is abundant but dissolved oxygen in water is less as compared to the atmosphere. Dissolved oxygen (DO) is a measure of the amount of oxygen dissolved in the water – (the amount of oxygen available to living aquatic life). The amount of dissolved oxygen in the aquatic system is also an indicator of water quality. A small amount of oxygen, up to about ten molecules of oxygen per million of water, is actually dissolved in water. Oxygen enters into the aquatic system mainly from the atmosphere and from **groundwater discharge.** The aquatic animals used this dissolved oxygen for breathing. Rapidly moving water bodies (mountain streams or large rivers) contain a lot of dissolved oxygen as compared to stagnant water. The amount of dissolved oxygen depends upon the amount of organic matter, temperature and partial pressure. Cold water can hold more dissolved oxygen as compared to warm water. In winter and early spring, the concentration of dissolved oxygen is high because the water temperature is low. In summer and fall, the concentration of dissolved oxygen is low because the water temperature is high. So, The aquatic environment has less amount of oxygen as compared to the terrestrial environment (one volume of water contains a little less than 4% the amount of oxygen present in the same volume of air). The respiratory gases are treated as ideal gases in the atmosphere As, CO_2 and O_2 have similar solubility in air. But in water the solubility of gases depends upon a) nature of the gas, (b) pressure of the gas in the gas phase, (iii) the temperature and (c) presence of other solutes. Therefore, the solubility of co2 in water is the same as in air but for O_2 it is about one-thirtieth the solubility in air. The Fish live in an aquatic environment which is dense and very viscous. In fish the main respiratory organ is gills. The low concentration of O2 in the water leads to evolutionary development of larger gill surface areas for effective gas exchange.

Gills are divided into two types

A) Internal gills
B) External gills

7.4 *ORGANIZATION OF GILLS*

In agnathan hagfishes and lampreys, elasmobranchs, and teleosts the gills are bilaterally situated on either side of the pharynx and are consist of a series of pouch-like or arch-like structures that provide the physical support to gill filaments known as primary lamellae. A row of regularly spaced filaments projecting posterolaterally lines the sides of the gill arches. Each row or stack of filaments form a hemibranch and a set of hemibranchs, one on each side of the arch, forms a holobranch. In teleost fishes the gills are made up of four such holobranch spaced between five branchial slits. However, elasmobranchs contain an extra hemibranch on the anterior side of the first branchial slit. The posterior side of the final branchial chamber does not have a hemibranch. In most teleost and elasmobranchs a reduced hemibranch is present known as pseudobranch, it is associated with the spiracles. The spiracles function as one-way valves for the entry of respiratory water. In case of the teleosts, the spiracles are lost but the pseudobranch is present. However in elasmobranchs, the spiracle is reduced in fast-swimming pelagic species, but enlarged in bottom dwelling species. The pseudobranch is not involved in gas exchange as other hemibranchs and in fact receives oxygenated blood. In the lampreys and elasmobranchs, the filaments throughout their length are supported by an interbranchial septum made up of a vertical sheet of connective tissues which run from arch to the outer body wall. But in the teleosts, the interbranchial septum is reduced and the majority of the distal length of the filaments is unattached. The individual gill arches in teleosts and elasmobranchs, is supported by the cartilaginous branchial skeleton that runs from the medial portion of each arch and but in teleosts it is partially calcified.

In the elasmobranchs, the interbranchial septum in elasmobranchs is supported with the help of skeletal branchial rays that extend from the main skeletal support in each arch. In the teleosts, the branchial rays are in the form of filaments which are associated with the abductor muscles, that help in the positioning of the filament in the water flow. The opposite hemibranchs filament tips in the branchial slit chambers come closer to each other and form a sieve-like structure. The surface area of dorsoventrally flattened filament is increased by secondary folding to form lamellae. The lamellae consist of a thin plate-like structure with a vascular core covered by a thin epithelium on either side.

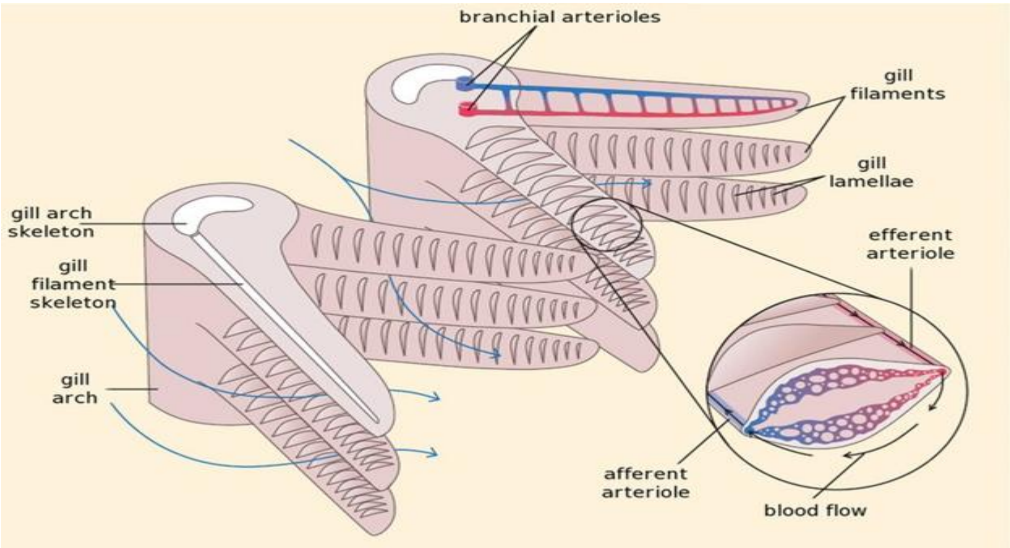

Figure 1.1 Gill structure (credit: https://commons.wikimedia.org/wiki/File:Fish_gill_structure.jpg)

7.5 *MECHANISMS OF RESPIRATION*

The respiration process involve various steps

1) Intake of water:- The simultaneous contraction of various muscles like coracomandibular (lower jaw muscles), Coracohyal (present anterior to the basihyal) and coracobranchial (present in the branchial arches) lead to opening of mouth, depression of buccal floor and lowing of pharyngeal floor. At the same time the contraction of horizontal muscle of the interbranchial septum leads to closing of external gill slits. The reduction in the pressure in the enlarged buccal and pharyngeal cavities, water rushes in through the mouth into these cavities.
2) Elimination of water:- the contraction of adductor mandibular muscle (extended between the upper and lower jaw) leads to closing of mouth. The external gill slits are opened due to the relaxation of the horizontal muscles of the interbranchial septum. The contraction of constrictor

muscles (present inner to the visceral arches of the interbranchial septum) leads to reduction of Buccal and pharyngeal cavities. This leads to increase in the internal pressure and forms the water through the internal gills into gill clefts. Then this water passes over the gill lamellae where the gaseous exchange occurs and then the water moves out of fish gills via external gill slits. During this process the oesophagien is kept closed by the muscle contraction to control the entry of water into it.

3) Gaseous exchange: The water enters via mouth into the pharynx and then into the gill clefts. As the water passes over the gill lamellae which contain the extensive system of the capillaries containing blood. The blood which is received from the different parts of the body is deoxygenated via afferent branchial arteries into capillaries. The oxygen from the water diffuses into the capillaries and at the same CO_2 from the deoxygenated blood diffuses into the outgoing water current. This water is then moved out via an external gill slit. The oxygenated blood is now distributed throughout the body via dorsal aorta.

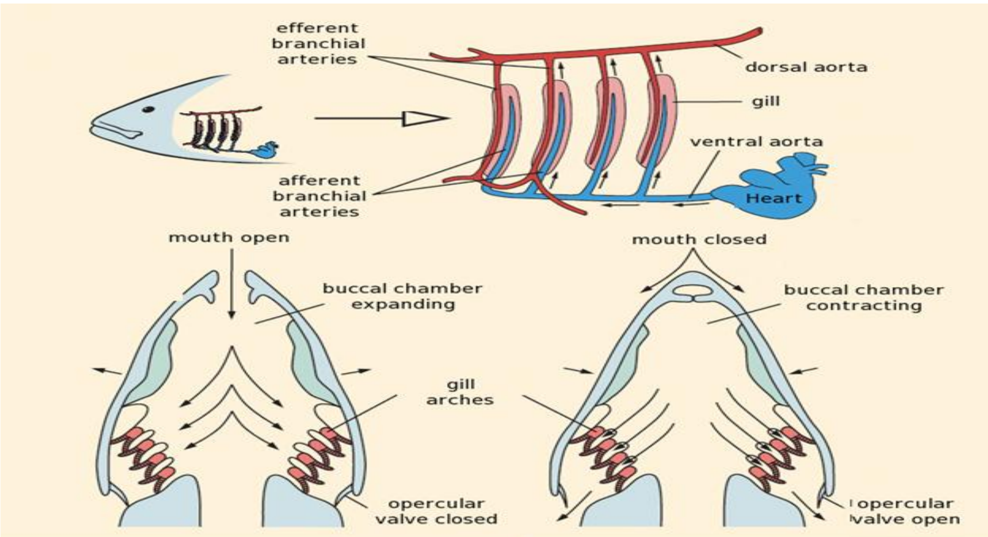

Fig 1.2 Process of respiration (credit:https://commons.wikimedia.org/wiki/File:Fish_gill_respiration.jpg)

7.6 *STRUCTURE OF A TYPICAL TELEOSTEAN GILL*

In teleosts the mouth is placed anterior and buccal contains a cavity with a pair of valves. These valves allow the water to enter into the cavity but not allow it to leave. The external gill slits are covered by a flap known as an operculum. The operculum is supported by various thin opercular bones.

In teleosts the gills are bilaterally situated on either side of the pharynx and consist of a series of pouch-like or arch-like structures that provide the physical support to gill filaments known as primary lamellae. A row of regularly spaced filaments projecting posterolaterally lines the sides of the gill arches. Each row or stack of filaments form a hemibranch and a set of hemibranchs, one on each side of the arch, forms a holobranch. In teleost fishes the gills are made up of four such holobranch spaced between five branchial slits. In most teleost reduced hemibranch is present known as pseudobranch, it is associated with the spiracles. The spiracles function as one-way valves for the entry of respiratory water. In case of the teleosts, the spiracles are lost but the pseudobranch is present. In the teleosts, the interbranchial septum is reduced and the majority of the distal length of the filaments is unattached. The individual gill arches in teleosts are supported by the cartilaginous branchial skeleton that runs from the medial portion of each arch, but it is partially calcified. In the teleosts, the branchial rays are in the form of filaments which are associated with the abductor muscles that help in the positioning of the filament in the water flow.

7.6.1 PHYSIOLOGY OF GILL RESPIRATION

Respiration occur in following steps

1) Respiration begins with opening of mouth by sternohyoid and elevator muscle of palatine. The operculum is closed frequently. At the same time, the branchiostegal rays are spread and lowered. The mouth cavity increases to generate negative water pressure in it. Water enters the mouth.

2) The area between the gills and the operculum is enhanced as the gill covers are abducted anteriorly. The opercular skin flaps are still closed posteriorly by the pressure from outside water. The reduced pressure in the gill cavity causes the water to flow over the gill.

3) The buccal and opercular cavities start to reduce, while the oral valves stop the flow of water out of the mouth.

4) Closed operculum with the opercular flaps has achieved its final state of abduction and water is drawn outside the gills. Then the opercula are rapidly brought towards the body causing the gill flaps to open and the water is expelled. The backward flow of water is prevented by excess pressure in the buccal-cavity as compared to the epibranchial cavity.

7.6.2 GILL VENTILATION

During the processes of respiration a continuous current of water is sustained through the buccopharyngeal cavity. For this, water is drawn into the buccal cavity and expelled via the external branchial aperture. Inhalation and exhalation of water in the buccal cavity causes purification of blood. Fishes utilise two different system for maintain a continuous supply of new water available 1) A complex double pump system 2) A simple system known as ram ventilation

1) DOUBLE PUMP SYSTEM

The flow of water is unidirectional. In teleosts generally 2 respiratory pumps (buccal and opercular) function in coordination with each other to push water via gills.

Phase I

Expansion of buccal and opercular cavities while opercula are closed

Phase II

Mouth closes, opercula open, forcing water across gills

RAM VENTILATION

Fishes e.g. Tuna swim with their mouth parts open at a high speed. During this no visible breathing movements occur and water flows continuously over the gills, this process is known as ram ventilation.

7.7GILL SURFACE AREA

Total gill surface area is the area of the respiratory epithelium in a fish that, in most species, is the bilateral surface of all the lamellae. Gill area (*A*) can be calculated using following equation:

$A = L_{fil} \times 2 n_{lam} \times A_{lam}$

L_{fil} is the total length of all the gill filaments,

n_{lam} is the lamellar frequency (i.e., the mean number of lamellae per unit length on one side of a filament, which is multiplied by two to account for lamellae on each side)

A_{lam} is the mean bilateral surface area of a lamella.

Another method for the calculation of gill surface area is stereological techniques. Randomly oriented gill tissue samples are fixed in glycol methacrylate and vertical sections through the tissue are mounted on slides and total gill volume is determined. Subsequent point counting of filament and lamellar tissue densities by a superimposed grid helps in calculation of their relative volumes and surface areas.

7.9 *WATER FLOW ACROSS THE GILLS*

In the process of respiration the floor of the buccal cavity is lowered and the mouth is opened. After that the water moves in to fill the greatly expanded buccal cavity. Then the mouth is closed and the pharynx contracts. The water then enters the gill-pouches and gaseous exchange occurs through gill-slits. The spiracles are sometimes used as accessory pathways for the entry of water, instead of the mouth when it is otherwise occupied.

7.8 COUNTER CURRENT PRINCIPLE

The gills in fishes use a mechanism known as counter-current flow for very effective removal of the maximum amount of oxygen from the water flowing over them. In this process two types of fluids (in this case blood and water) with different concentrations of one or more dissolved substances flow in opposite directions past one another. These fluids are separated by thin membranes. This helps in diffusion of a substance (such as oxygen) down its concentration gradient from one fluid (water) to the other (blood). 80 to 90% oxygen is absorbed from the water.

7.10 *GAS EXCHANGE*

The gills are very vascular structures, which have afferent and efferent branchial arteries. The afferent branchial artery which is present superficially on the outer edge of the gill carrying the deoxygenated blood. This artery breaks-up into capillaries in the gills.

During the flow of water through the gill-slits, the deoxygenated blood present in the capillaries of the gill-filaments takes up the oxygen from the water and gives out carbon dioxide by the process of diffusion. The oxygenated blood is collected by efferent branchial arteries and is transported to the different parts of the body.

As the O_2 diffuses very slowly from one liquid into another the red blood cells containing haemoglobin (In vertebrate) carry gas effectively. Haemoglobin is a respiratory pigment. It is made up of four subunits, each with a heme group and a globin chain. The heme group is composed of a porphyrin ring which contains an iron (Fe) atom in its centre. The Fe is in the +2 redox state (ferrous) and can reversibly bind to the oxygen.

The haemoglobin molecule contains four binding sites for oxygen via the iron atoms in the four heme groups. So, each Hb tetramer can bind four oxygen molecules.

The diffusion rate of CO2 in water is high as compared to O2 therefore, low amount of free CO2 in water favours waste gas elimination at the gill by diffusion.

7.11 *AIR-BREATHING FISHES: CAUSATIVE FACTORS AND STRUCTURAL ADAPTATIONS*

Around 450 species are known for their capacity to obtain oxygen from atmospheric air, Air breathing adaptation might be a result of aquatic hypoxia in freshwater habitats, and periodic emersion in marine habitats. All the air breathing fishes are bimodal breathers meaning they retain gills. Example of an air-breathing organ is the skin that can take up oxygen from air when the animals emerge, and the gills collapse and no longer function for oxygen uptake. Air-breathing fishes have capability to gulp air and store it in well-vascularized internal organs e.g. true lung, a modified swimbladder, diverticula of the buccal, opercular or pharyngeal cavities, or the gut. These modified organs help fishes in respiration not only when exposed to air but also when in water. Generally the majority of air-breathing fishes are found in the tropics but they can also inhabit temperate areas. Examples of air breathing fishes are plesiomorphic bony fish species such as the bichirs Polypterus spp, the bowfin Amia calva L. and the gars Lepisosteus spp., and some primitive teleosts, osteoglossidae like Arapaima gigas and elopiformes like Megalops spp. Air-breathing fishes may be tolerant to ammonia

7.11.1 ACCESSORY RESPIRATORY ORGANS AND RESPIRATORY EPITHELIUM

Fishes which lives in shallow stagnant freshwater of tropical areas, where water deoxygenation occurs has developed accessory respiratory organs. Also in torrential streams of the hills, which generally dry up in the summer season.

1. **Buccopharyngeal epithelium: this primitive adaptation present in** Monopterus javanensis, Electrophorus electricus, Periophthalmus sp and Boleophthalmus sp. In this case, the epithelial lining present in the mouth cavity is highly vascular and forms a vascular network for effective respiratory.
2. **Skin:** In eels (Anguilla anguilla), the moist skin which is highly supplied with blood help in aerial respiration.
3. **External gills: External gills are ectodermal in origin.** They are a greatly vascular and filamentous structure covering the outer surface of the visceral arches or visceral skeleton. They are in direct contact with water, which helps in respiration.
4. **Labyrinthiformis organs:** Anabas testudineus and Trichogaster fasciatus are known to contain this organ. They are formed within the extra branchial chambers enclosed between the gills and the operculum.
5. **Opercular lungs: These are bag** like diverticula is called opercular lungs or air chambers present in advanced air breathing teleosts. They are formed from the dorsal surface of the branchial chamber or opercular chamber. The opercular lungs are found above the gills and contains specialised structures known as **rosettes** or **arborescent organs** (arbo = tree) to enhance the respiratory surface e.g. Clarias, H. fossilis, A. testudineus, T. fasciatus etc.
6. **Air bladder/ swim bladder**: Swim bladder is a gas filled bag like structure which originates from the it is formed from dorsal outgrowth from the alimentary canal and situated between the gut and kidney. in most of the ray finned fishes. It helps in controlling buoyancy at different depths in water bodies. The gases that are found in the air bladder are oxygen, carbon dioxide and nitrogen. The fishes having air bladders have adapted to extreme drought conditions. The teleosts like Chirocentrus, Cyprinids come to the surface, take air and pass it back to the air bladder that is very vascular.
7. **A special part of alimentary canal**: In a small group of fishes, the alimentary canal is modified for respiration. Modification includes reduction in muscle layers of stomach and intestine leading to its thinning and making it transparent. Inner surface is lined by a single layer of epithelial cells that is greatly supplied with blood. So, here the inhaled air is swallowed and forced back inside

the alimentary canal. After respiratory exchange, the used up air is either passed outside via the anus or is expelled through the mouth.

7.12 *SUMMARY*

The respiratory process is the process of gaseous exchange between environment and the organism. The gases exchange between the environment and respiratory organs of organisms is termed as external respiration and the gases exchange between blood and the cells of the organism is termed as internal respiration. The Fish live in an aquatic environment which is dense and very viscous. In fish the main respiratory organ is gills. The low concentration of O2 in the water leads to evolutionary development of larger gill surface areas for effective gas exchange. In agnathan hagfishes and lampreys, elasmobranchs, and teleosts the gills are bilaterally situated on either side of the pharynx and are consist of a series of pouch-like or arch-like structures that provide the physical support to gill filaments known as primary lamellae.During the processes of respiration a continuous current of water is sustained through the buccopharyngeal cavity. For this, water is drawn into the buccal cavity and expelled via the external branchial aperture. Inhalation and exhalation of water in the buccal cavity causes purification of blood. Total gill surface area is the area of the respiratory epithelium in a fish, that, in most species, is the bilateral surface of all the lamellae. Around 450 species are known for their capacity to obtain oxygen from atmospheric air, Air breathing adaptation might be a result of aquatic hypoxia in freshwater habitats, and periodic emersion in marine habitats. Air-breathing fishes have capability to gulp air and store it in well-vascularized internal organs e.g. true lung, a modified swimbladder, diverticula of the buccal, opercular or pharyngeal cavities, or the gut.

7.13 *TERMINAL QUESTIONS AND ANSWERS*

1) Respiratory organ in fishes

a. Gills
b. Lungs
c. none of the above
d. Both of the above

2) Gills are of two types

a. Open and close
b. Internal and external
c. Large and small
d. All of the above

3) Gill filament are known as

a. Stalk
b. Lamellae
c. Filter
d. none of the above

4) Where does oxygen diffuse take place?

a. Gill arch
b. Operculum
c. Gill lamellae
d. Gill comb

5) Accessory respiratory organs in fishes are

a. Skin
b. Air bladder
c. Labyrinthiformis organs.
d. All of the above

Answer: 1 (a), 2(b), 3(b), 4(c) and 5(d)

6. Write a short note on

a) Gills
b) Aquatic respiration
c) Structure of teleostean gills

7. Describe the organisation of gills in fish.

8. Explain the mechanisms of respiration in fish.

9. Describe the process of gas exchange in fish.

10. Describe various accessory respiratory organs.

11. What is Gill ventilation?

12. What is the counter current principle?

7.14 *REFERENCES*

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UNIT 8: EXCRETORY SYSTEM AND OSMOREGULATION

Content

8.1 OBJECTIVES

After studying this unit learns will learn:

1. Structure and functions of the kidney, nitrogenous waste and excretion
2. Glomerular and aglomerular kidneys
3. Excretion of nitrogenous wastes, water and ion balance
4. Urea cycle
5. Osmoregulation in Fish
6. Stenohaline teleosts
7. Euryhaline teleosts
8. Migratory teleosts
9. Water and electrolyte regulation in marine, freshwater and euryhaline fishes

8.2 STRUCTURE AND FUNCTIONS OF THE KIDNEY, NITROGENOUS WASTE AND EXCRETION

The main organ involved in the excretion process is the kidney. Mammals and fish kidneys differ from each other. Fish kidneys are paired, smaller, soft, narrow, stretched, and extended reddish-brown structures. It is situated at the vertebral column enclosed by coelomic epithelium. The location and type of kidney is different in different types of fish. The nephron is the functional unit of the kidney. Nephron is composed of the glomerulus and renal tubule. The glomerulus is a cluster of capillaries via which the glomerular filtrate is passed. The tubule in fishes is divided into a Bowman's capsule which surrounds the glomerulus and a series of segments known as 1) proximal I 2) proximal II 3) distal 4) collecting duct.

Two types of kidney are found in fish 1) Pronephric and 2) Mesonephric. Ogawa in 1961 divided the teleostean kidney into five classes. Teleosteos have “head kidney” and “trunk kidney”. The head region (contains the pronephric part) and trunk region (contains the mesonephric part). The teleost fish is made up of bundles of nephrons along with glomeruli, renal tubule, the corpuscle, and collecting ducts. The two areas of archinephric ducts are linked at the posterior end of the kidney.

Functions

The kidney plays an important role in osmoregulation. The maintenance of body fluid and salt concentration is mandatory for the survival of an organism. Fish is an aquatic animal and live in different water bodies (freshwater and marine water). So, fish kidney help in maintaining water-salt concentration in different environments.

In freshwater the fish kidney control the extra loss of solute to maintains high amount of salt in their bloodstream as compare to water bodies. The water from the surrounding enters into the fish body by the process of osmosis. To counter the water absorbed by the skin, the kidney excretes the excess water by the process of excretion to maintain salt concentration inside the body.

In the marine water system, the water contains a higher concentration of salt as compared to fish bodies. So, water moved out of the fish body by the process of osmosis. To counter water loss the fish drink water and using it for the functioning of kidneys. The kidney excretes excess salt by the process of excretion to retain the water inside.

Urine consists of water and other solutes (creatine, creatinine, urea, ammonia, and other nitrogenous waste products). The gills also help in excretion of ammonia. Few fishes have a urine storage organ known as "urinary bladder", but it is a posterior evagination of the mesonephric ducts, so it mesodermal in origin so, not homologous to urinary bladder of tetrapod's which endodermal in origin.

8.3 GLOMERULAR AND AGLOMERULAR KIDNEYS

In vertebrates three types of kidneys are found: - 1) pronephros (larval fishes), 2) mesonephros (Actinopterygii), and 3) metanephros (tetrapods).

The pronephros has nephrostomes; anterior funnels which vacant into the body cavity through pronephric tubules. Adult hagfishes have anterior pronephros and a functional posterior mesonephros kidney. Lampreys till they reach 12-15mm have a pronephros then until they reach by metamorphosis they develop a mesonephros. A pronephros is considered a transitional kidney as it appears during ontogenetic development in actinopterygian larvae and then is replaced by a mesonephros in adult fish.

The mesonephros is a complex form of kidney that does not have funnels that are vacant into the body cavity. The mesonephro have a number of renal corpuscles, each of which is made up of glomerulus surrounded by a Bowman's capsule. The glomerulus obtains blood from an afferent arteriole from the dorsal aorta. The glomerulus is an ultrafilter which removes water, salts, sugars, and nitrogenous wastes from the blood. The filtrate is collected in Bowman's capsule and then for reabsorption of water, sugar and other solute it passes through mesonephric tubule.

Few fishes are aglomerular which means they lack glomeruli in their kidneys. At least 30 species of aglomerular teleost`s are known from seven different families e.g. Batrachoididae, Ogcocephalidae, Lophiidae,Antennariidae, Gobiesocidae, Syngnathidae, and Cottidae, most of them are marine. Aglomerular kidneys are not able to excrete sugars.

8.4 EXCRETION OF NITROGENOUS WASTES, WATER AND ION BALANCE

In fish excretion is not only performed by the kidney but digestive tract, skin, and especially the gills (ammonia excretion) also help in excretion. Fish live in water which has a specific concentration of dissolved solute, so maintenance of a constant internal environment (homeostasis) is necessary for fish survival. The kidney plays an important role in osmoregulation in the fishes. Marine and freshwater fishes have considerable differences in their kidney structure because they live in aquatic environments (solution) having different solute concentrations. Kidneys of freshwater fishes are larger kidneys and glomeruli (10,000 per kidney) measuring up to 48–104 μm across. The glomeruli of marine fishes are 27–94 μm across. The kidney of freshwater fishes excretes large amounts of water to counterbalance the water absorbed by the skin. Fishes that live in freshwater tend to lose salt to the environment and must replace it. These fishes absorb some salt from their food and also via gills and skin inside the mouth actively when water passes through the mouth. This absorption of salt occurs with the help of special cells which can move the salts against the diffusion gradient. These fishes drink very little water and absorb less water from their food.

It is very important for Marine fishes to conserve water, so their kidneys excrete little water. They maintain their water balance by drinking large amounts of seawater and retaining most of the water and excreting the salt. In them nitrogenous waste in the form of ammonia is excited by gills. Special cells known as chloride cells are used for the excretion of salt.

Marine fishes (e.g. hagfishes, sharks, and rays) have blood osmotic concentrations equal to that of seawater so they don't need to drink water to maintain their osmotic balance. Sharks and rays maintain their osmotic concentration high by retention of urea in the blood. Freshwater fishes excrete generous amounts of highly dilute urine to prevent “waterlogging” caused by the large amount of water diffusing in via all semipermeable membranes. Marine fishes drink sea water to prevent dehydration and excrete less highly concentrated urine.

Many fishes are ammonotelic however few species can detoxify ammonia to glutamine or urea. Some fish species are able to accumulate high levels of ammonia in the brain or have defense against ammonia toxicity by increasing the effectiveness of ammonia excretion by active NH+4transport, manipulation of ambient pH, or by decreasing the permeability of ammonia through the branchial and cutaneous epithelia.

8.5 UREA CYCLE

The water and ion regulation is different in seawater as compared to freshwater. Elasmobranchs, holocephalans and coelacanths accumulate urea as an osmolyte. The urea is synthesized by ornithineurea cycle (OUC) and helps in osmoregulation. Marine elasmobranchs are ureogenic as they have a functional OUC in mitochondria of liver and muscle cells. In these fishes urea is the primary product (>50%) of nitrogen excretion and they are also ureotelic. In these cartilaginous fishes effective urea permeability is reduced in order to retain urea with the help of specific secondarily active (Na^+ coupled) urea transporters in gills and kidney. Modification of lipid composition of gills to create higher cholesterol:phospholipid ratios also help in the above process.

The enzymes of OUC in ureogenic fishes are Carbamoyl Phosphate synthetase III (CPS III), ornithine transcarbamoylase (OTC), argininosuccinate synthetase, argininosuccinate lyase and arginase. The main ammonia-fixing enzymes e.g. GS (Glutamine synthetase), CPS III, and OTC are present in the matrix of liver mitochondria. CPS III enzyme uses glutamine as a substrate that is why ureogenic fishes have high levels of GS in liver mitochondria. NH_3 is detoxified to proton-neutral glutamine; this glutamine is converted to carbamoyl phosphate by CPS III in the liver mitochondrial matrix of fish which cannot be regarded as an ammonia-detoxifying system. While in higher vertebrates OUC involves the enzyme CPS I which uses NH_3 directly as a substrate. In case of marine elasmobranchs, the localization of GS and CPS III in the liver mitochondrial matrix might have evolved more as a mechanism for urea synthesis for osmoregulatory reasons. Therefore, glutamine is utilized directly for carbamoyl phosphate, and ultimately urea synthesis, instead of leaving the mitochondria to act as a substrate for other anabolic cycles in the cytosol. As the cycle progresses with the help of enzyme GS, CPS III, and OTC to form citrulline in the matrix, which then exits the mitochondria. Citrulline is converted to arginine by enzymes argininosuccinate synthetase and argininosuccinate lyase in the cytosol. Unlike mammals, arginase is found in the mitochondrial matrix of fish (except lungfishes) so, arginine has to re-enter the matrix then it is converted to urea, regenerating ornithine for citrulline synthesis.

Few teleosts e.g. the gulf toadfish *O. beta* are ureotelic and excrete more than 50% of the nitrogenous wastes as urea or able to detoxify a minor quantity of ammonia to urea during ammonia-loading. Ureogenesis uses a significant amount of energy and 5 mol of ATP are used for each mole of urea synthesized while 2.5 mol of ATP used for each mole of nitrogen assimilated in teleosts and elasmobranchs.

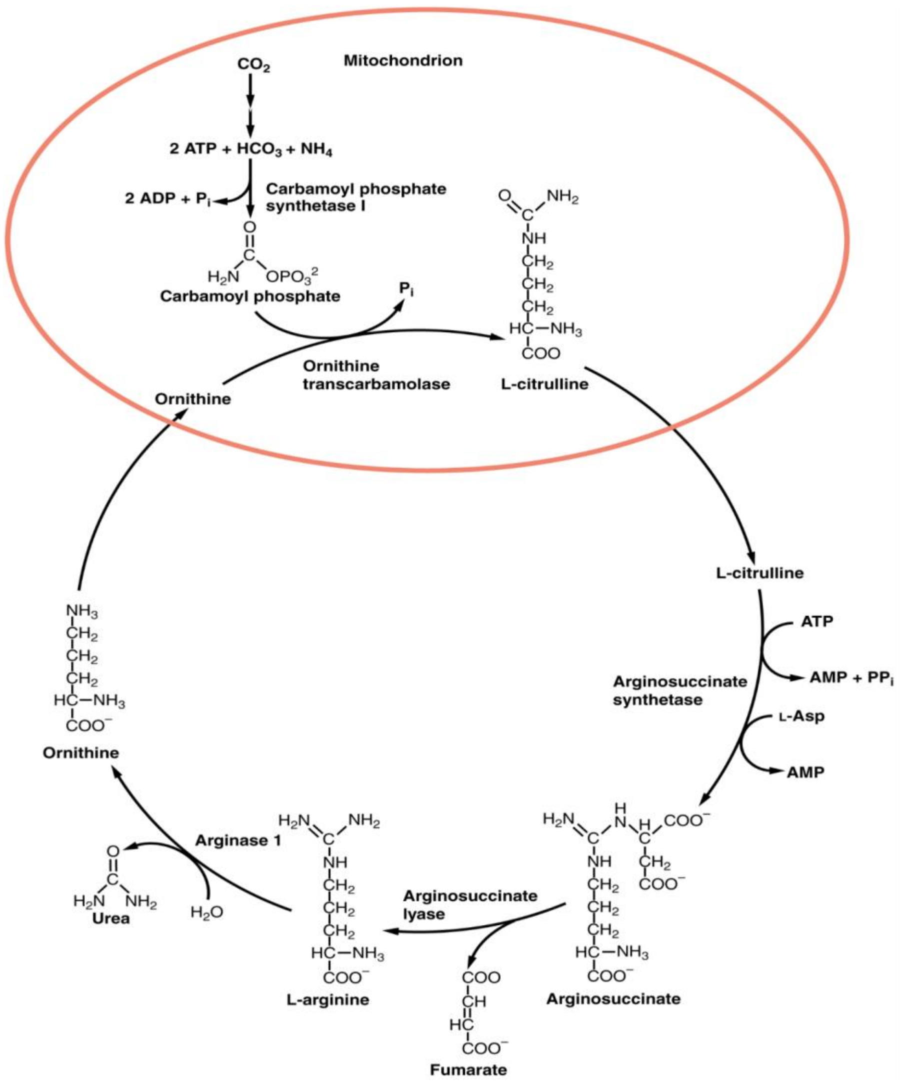

Fig 8.1 Urea Cycle (credit: https://upload.wikimedia.org/wikipedia/commons/0/0a/2518_Urea_Cycle.jpg)

8.6 OSMOREGULATION IN FISH

Regulation of body fluid is important for all organisms to survive in their respective habitats like freshwater (FW), seawater (SW), and terrestrial environments. In the freshwater which is highly hypoosmotic, fish face the two problems 1) osmotic water loading and 2) salt depletion. To maintain homeostasis, NaCl is replaced by active uptake across the gill, and osmotic water loads are excreted with the help of the kidney. Freshwater fish and euryhaline fish kidney consist of nephron: glomerulus, proximal tubule, distal tubule, and collecting duct. Glomeruli and the urinary bladder help in the renal excretion of water. Glomerular filtration carries huge volumes of extracellular fluid to the kidney. The successive reabsorption of filtered salts without water in the distal nephron and urinary bladder conserves volume for elimination.

In the sea water which is a highly hyperosmotic environment, here the fish lose water by osmosis and gain salt by diffusion. The lost body water is replaced by consuming lots of sea water. Gills help in

excretion of ingested NaCl and kidney excrete the ingested divalent ions, Mg, Ca, and SO4. In stenohaline seawater fish the size and function of glomeruli is less or absent So, the divalent ions excretion is done by renal tubules rather than glomeruli.
The teleost fish regulate their plasma Na^+ and Cl^- concentrations and osmolality at levels about one-third of SW. To adapt to marine water high-salinity the cartilaginous fishes e.g sharks, skates, rays, and chimeras have urea-based osmoregulation mechanism. Their kidneys reabsorb nearly all filtered urea from the primary urine. These fishes have complex nephron system in the kidney like the four-loop configuration of each nephron, the occurrence of distinct sinus and bundle zones, and the sac-like peritubular sheath in the bundle zone, Cartilaginous fishes regulate plasma ions to levels approximately one-half of surrounding SW while they store high concentrations of the urea as an osmolyte (known as ureosmotic strategy). So, their body fluids are slightly hyperosmotic to surrounding SW and this prevents dehydration in cartilaginous fishes even in the high-osmolality SW environment. The high concentration of urea in the body is maintained by the ornithine urea cycle (OUC).

Elasmobranchs are divided into three groups on the bases of their osmotic capacities

1) stenohaline marine species, 2) stenohaline FW species, and 3) euryhaline species.

Generally the elasmobranchs live in salt water (SW) and are not able to survive in freshwater (FW). In sturgeons, three types are categorized depending on salinity, each with increasing levels of salinity tolerance. Stenohaline species e.g. lake sturgeon have tolerance for a narrow range of salinities but usually inhabit a single salinity throughout their life. Euryhaline and anadromous species e.g. Adriatic sturgeon can live in a wide range of salinities, spawn in freshwater, migrate to brackish/estuarine water as juveniles, grow-out and then return to freshwater to spawn as adults. Amphihaline and diadromous species e,g, green sturgeon can live in freshwater and seawater, spawn in freshwater and migrate to full-strength seawater to grow-out prior to returning to freshwater to spawn as adults.

8.7 STENOHALINE TELEOSTS

Most of the fishes are stenohaline. Stenohaline fishes spend all their life in water of nearly constant salt concentration; Fish skin is quite impermeable for water and ions. The gills have a large surface which is permeable epithelium and is in contact with the surrounding aquatic environment.
Freshwater fish have blood osmolalities higher than the surrounding water, So, passive influx of water and efflux of ions. This condition is reversed in SW teleost. These fish maintain their blood ionic composition by active processes. Two strategies are used by these fishes to maintain osmolarity

1) stop the passive efflux of ions by diffusion and loss from urine
2) removal of excess water

In lampreys and teleosts, the loss of ions is compensated by salt intake in the food and by gills ions uptake. The water balance is maintained by drinking less water and by excreting copious urine. At gills due the excretion of water product ammonia various exchange mechanisms are coupled like chloride is taken up in exchange for bicarbonate, and sodium is taken up in exchange for protons and/or ammonium ions. Teleost kidneys consist of typically segmented mesonephros. In Freshwater teleosts kidney help in getting rid of water which enters passively via gill by producing dilute urine. In SW teleosts, the kidney helps excretion of divalent cations (Ca^{++} and Mg^{++}), excess hydronium ions and a few other minor waste products, but plays no role in water balance. As SW fish have to conserve water and the piscine kidney cannot generate urine which is more concentrated in comparison with body fluids, urine flow is kept to a minimum. In fact many marine teleosts have evolved an aglomerular kidney to minimize water loss. Urine formation starts with the production of glomerular filtrate. Glomerular filtrate is formed when the permeable capillaries of the glomerulus "leak" water, salts, glucose, amino acids, and small protein molecules. Some marine teleosts have no glomeruli and therefore they do not produce filtrate and urine. This filtrate is collected in the Bowman's capsule and then moved down the tubule. In tubule selective addition and removal of solutes of solute occur urine is produced from blood filtrate.

Filtrate passes through the ciliated neck to proximal segment I (PSI) where, glucose and other desirable larger molecules are absorbed out of the filtrate and low amounts of anionic organic waste products are pumped in. In PSI and PSII tubules are permeable to water and water follows the solutes out of the filtrate with no change in the osmotic pressure of the filtrate. PSII helps in controlling divalent cations. In FW teleosts, the divalent cations in the filtrate are recovered while SW teleosts cations are excreted into the waste water.

In distal segment (DS) and collecting tubule (CT) Na^{+} and Cl^{-} are pumped back out of the filtrate. FW and SW teleosts have different permeability in DS and CT. In case of FW teleosts, the walls are impermeable to water, so ions can be reabsorbed without water following, but SW teleosts the walls are permeable so water will follow the salts. This allows FW teleosts to produce a urine that is much more dilute than the blood. In case of SW teleosts, the tubules are permeable so the urine, which has a different ion concentration than the filtrate, will differ little in osmotic pressure.

8.8 EURYHALINE TELEOSTS

Fish which are able to move between freshwater and seawater are called euryhaline. Catadromous species e.g. eels move from freshwater to spawn in the sea and anadromous species e.g migrate to spawn in freshwater.

As we already know that FW and SW teleosts differ in their kidney function 1) glomerular filtration rate (GFR) is higher in FW teleosts, 2) in PSII, FW teleosts pump divalent cations out of the filtrate while SW teleosts pump them in, and 3) the DS and CT are impermeable in FW teleosts and permeable in SW teleosts. So, for euryhaline teleosts it is necessary to change kidney function in these three ways when they move from freshwater to saltwater and back.

8.9 MIGRATORY TELEOSTS

There are numerous teleosts like salmon—that travel between freshwater and seawater. They are able to adjust to the reversal of osmotic gradients. They adjust their biological processes by living in the intermediate brackish environment for some time.

8.10 WATER AND ELECTROLYTE REGULATION IN MARINE, FRESHWATER AND EURYHALINE FISHES

The organism has to maintain a balance with its environment and in order to maintain homeostasis (constant internal environment) a number of adaptations are required. The osmoregulation (active regulation of the osmotic pressure to maintain the fluid balance and concentration of salts) is essential for survival of fish in aquatic environments. In the case of freshwater fishes the salt concentration inside their body is higher as compared to surrounding water so water enters into the body by the process of osmosis. So to compensate for the excessive water entry a large amount of urine is produced by the kidney and at the same time salt is lost. To maintain the salt concentration special gill cells (chloride cells) take up ions from the water and transport it to blood.

In the case of marine fishes the salt concentration in their blood is much lower as compared to the surrounding seawater. These fishes constantly lose water and build up salt so, to compensate for the water loss, they continually drink the seawater. They produce small amounts of urine and their chloride cells of gills excrete that salt which is opposite to that of freshwater fishes.

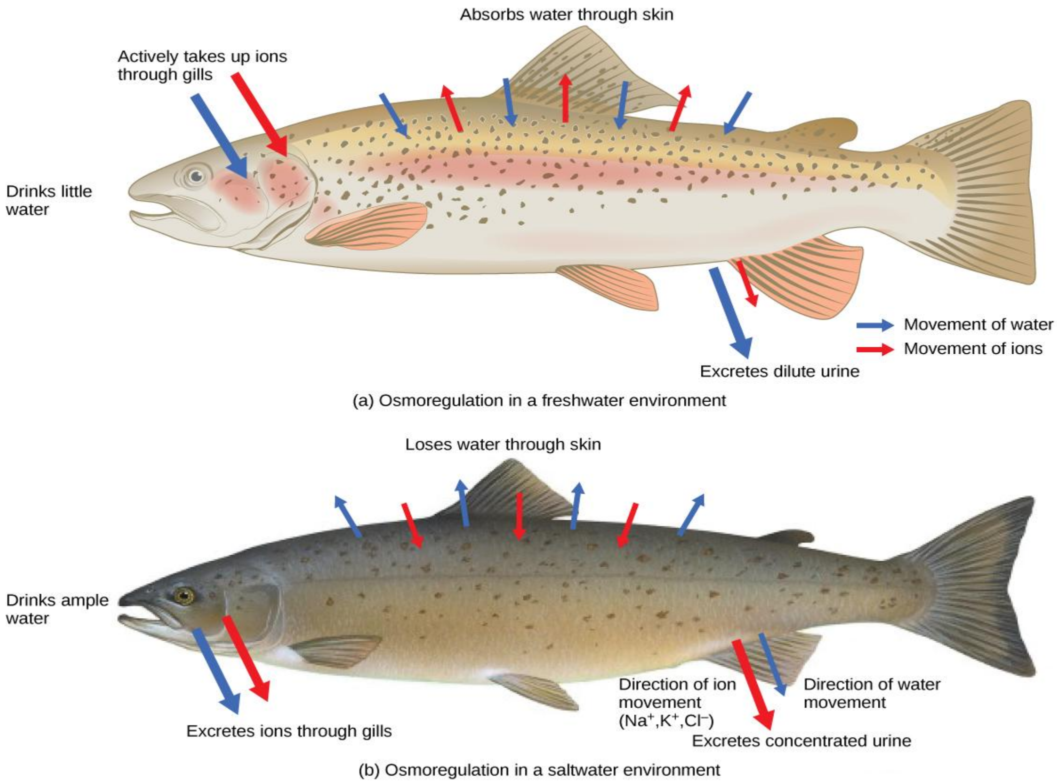

Fig 8.2. Osmoregulation in freshwater and marine fishes (credit: https://upload.wikimedia.org/wikipedia/commons/9/94/Figure_41_01_02ab.jpg)

Euryhaline organisms are able to adapt to a wide range of salinities. An example of euryhaline fish is salmon. A young salmon begins its life from a freshwater river and in freshwater it prepares for life in a salty ocean. Three changes took place before this happened. 1) It has to start drinking large amounts of water, 2 the kidneys must decrease urine production dramatically. And 3) the chloride cells in the gills must shift into reverse, meaning pumping sodium out instead of in. At some point, adult salmon come back to their birth place (spawn). By re-entering the freshwater river, the above-mentioned processes have to revert back. For a few days they stay in the estuarial zone as these changes happen automatically.

8.11 SUMMARY

The main organ involved in the excretion process is the kidney. Mammals and fish kidneys differ from each other. Fish kidneys are paired, smaller, soft, and narrow, stretched, and extended reddish-brown structures. It is situated at the vertebral column enclosed by coelomic epithelium. The location and type of kidney is different in different types of fish. The nephron is the functional unit of the kidney. The kidney plays an important role in osmoregulation. The maintenance of body fluid and salt concentration is mandatory for the survival of an organism. Fish is an aquatic animal and live in different water bodies (freshwater and marine water). So, fish kidney help in maintaining water-salt concentration in different environments. In vertebrates three types of kidneys are found: - 1) pronephros (larval fishes), 2) mesonephros (Actinopterygii), and 3) metanephros (tetrapods). The **pronephros** has **nephrostomes**; anterior funnels which vacant into the body cavity through pronephric tubules. The **mesonephros is a complex form of kidney** that does not have funnels that are vacant into the body cavity. In fish excretion is not only performed by the kidney but digestive tract, skin, and especially the gills (ammonia excretion) also help in excretion. Fish live in water which has a specific concentration of dissolved solute, so maintenance of a constant internal environment (homeostasis) is necessary for fish survival. The kidney plays an important role in osmoregulation in the fishes. The water and ion regulation is different in seawater as compared to freshwater. Elasmobranchs, holocephalans and coelacanths accumulate urea as an osmolyte. The urea is synthesized by ornithineurea cycle (OUC) and helps in osmoregulation; Most of the fishes are stenohaline. Stenohaline fishes spend all their life in water of nearly constant salt concentration, euryhaline organisms are able to adapt to a wide range of salinities. An example of euryhaline fishes is salmon.

8.12 TERMINAL QUESTIONS AND ANSWERS

1. Excretion in fishes occur at

a) Gill

b) Kidney

c) Both gills and kidney

d) None of above

2. Euryhaline fishes are

a) Euryhaline organisms are able to adapt to a wide range of salinities.

b) Can only survive in freshwater

c) Can only survive in sea water

d) None of the above

3. Stenohaline fishes are

a) Migratory teleost

b) Stenohaline fishes spend all their life in water of nearly constant salt concentration

c) Stenohaline fishes spend their life in water of different salt concentration

d) None of above

4. Ornithine urea cycle (OUC) synthesized

a) Amino acid

b) Protein

c) Urea

d) Lipid

Answer: 1 (c), 2(a), 3(b) and 4(c)

5. Write a short note on

a) Water and electrolyte regulation in marine, freshwater

b) Glomerular and aglomerular kidneys

6. Write about the urea cycle.

7. Describe the process of osmoregulation in fishes.

8. Explain the process of excretion in fishes.

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UNIT 9: NERVOUS AND SENSORY SYSTEM

Contents

9.1 OBJECTIVES

After studying this unit learners will learn:

1. Structure and functions of the brain and cranial nerves
2. Receptors
3. Anatomy and function of the Mauthner neurons
4. Structure and functions of the sense organs: eye, visual pigments and vision
5. Chemoreceptors: Olfactory, gustatory and electroreceptors
6. Biological significance of chemoreception
7. Acoustico-lateralis system

9.2 INTRODUCTION

Fish have a well-developed nervous system that allows them to perceive and respond to their environment. While their nervous system is less complex compared to mammals and birds, it is still highly specialized for their aquatic lifestyle. The nervous system of fish consists of the central nervous system (CNS) and the peripheral nervous system (PNS). The CNS includes the brain and the spinal cord, while the PNS consists of nerves that extend throughout the rest of the body. Fish brains vary in size and complexity among different species. However, they generally have similar structures, including the forebrain, midbrain, and hindbrain. The forebrain is responsible for processing sensory information, olfaction (sense of smell), and certain behaviors. The midbrain coordinates sensory input and motor responses. The hindbrain controls vital functions such as respiration, digestion, and motor coordination. Fish have various sensory organs that allow them to detect their environment. They possess eyes for vision, which can vary in complexity depending on the species. They also have a lateral line system, which is a series of sensory organs along the sides of their bodies. The lateral line system enables fish to detect changes in water pressure and vibrations, helping them navigate, locate prey, and avoid obstacles. Additionally, fish have a keen sense of smell facilitated by olfactory organs called olfactory rosettes. These rosettes are responsible for detecting chemical cues in the water, aiding in locating food, identifying mates, and recognizing their surroundings. The PNS of fish consists of cranial and spinal nerves that relay information between the CNS and the rest of the body. These nerves transmit sensory information from the external environment to the brain and carry motor signals from the brain to the muscles for movement. Overall, the nervous system of fish is adapted to their underwater environment and allows them to sense and respond to stimuli in order to survive and thrive in their aquatic habitats.

9.3 STRUCTURE AND FUNCTIONS OF THE BRAIN AND CRANIAL NERVES

The nervous system is derived from ectoderm and divided into 3 parts 1) Central nervous system, 2) Peripheral nervous system and 3) Autonomous nervous system. The branch of science that studies the nervous system is known as neurology.

Central nervous system

The nervous system is a complex system. The brain is formed due to enlargement of the cephalic end of the spinal cord. The brain does not occupy the entire cranial cavity so, the space between brain and the cranium is filled with a gelatinous material. The size of the brain varies from species to species. In teleost the brain is divided into 3 regions 1) fore brain 2) midbrain and 3) hindbrain

Fore brain (prosencephalon)

The forebrain is made up of telencephalon and diencephalon. The anterior part of the brain is telencephalon and it mainly involves in the reception and conduction of smell. It is made up of a pair of solid olfactory lobes and two large cerebral hemispheres.

The forebrain is made up of telencephalon and diencephalon. The anterior part of the brain is telencephalon and it mainly involves in the reception and conduction of smell. It is made up of a pair of solid olfactory lobes and two large cerebral hemispheres. The cerebral hemispheres are made up of solid masses and covered by a thin membranous pallium. The two cerebral hemispheres joined with each other in the midline. Another important role of telencephalon is in controlling reproductive and parental behavior in fishes. Telencephalon connects to diencephalon by a large bundle of fibres known as anterior commissure. The narrow space between thin roof and solid hemisphere is considered the first and second brain ventricles.

The diencephalon is a median diamond shaped area between cerebral hemispheres and optic lobes. It is divided into three parts 1) epithalamus 2) thalamus and 3) ventral hypothalamus. The epithalamic region consists of two ganglionic masses called the habenulae. From the diencephalon roof arises a pineal body as an evagination. The cavity of diencephalon is known as the third ventricle of the brain. Ventral side of the diencephalon consists of hypothalamus and infundibulum. The hypothalamus is an endocrine gland connected to the brain by a stalk. The infundibulum enlarges laterally to form a pair of bean shaped structures known as inferior lobes. They are placed ventral and opposite to the optic lobes. Diencephalon has a large number of significant nuclei and several fiber tracts that connect it with different parts of the brain. It is a central for correlation for afferent and efferent impulses.

Midbrain (Mesencephalon)

The midbrain is made up of dorsally placed optic tectum and the ventral tegmentum. The tectum is formed from two optic lobes and in it five different zones are formed due to cells of different size and shape. Optic nerve fibers end in the tectum and an image formed on the retinal is projected on it. The optic tectum in fishes helps in reception and elaboration of visual sensation and correlates them with the muscular responses in organisms. It is also associated with learning.

Hindbrain (metencephalon)

The metencephalon is consist of cerebellum and it is a large dorsal out growth. It has corpus cerebelli externally and its anterior portion enters into optic lobes cavity to from valvula cerebelli. The corpus cerebilli is made up of an external molecular layer and an internal granular layer. The layers are reversed in case of valvula cerebelli. Cerebellum help in maintaining posture during swimming by coordinating with muscular activities. Myelencephalon or medulla oblongata ia the last part of brain and it cavity is known as fourth ventricle of brain. It is broad in front and has one median facial lobe and two lateral vagal lobes. Vagal lobes are gustatory center.

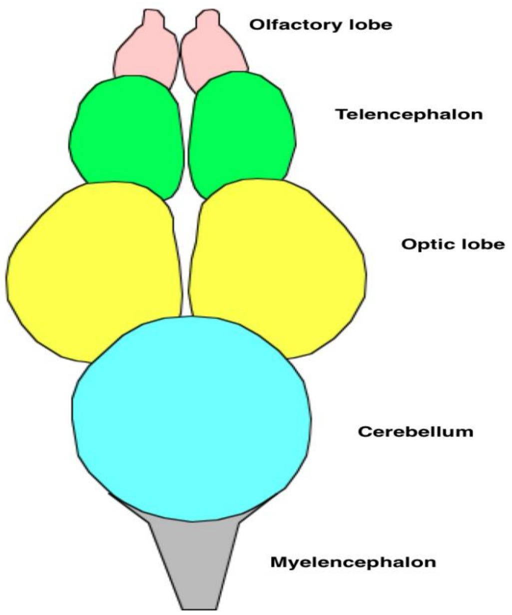

Fig 9.1 Fish brain (credit:-https://upload.wikimedia.org/wikipedia/commons/9/9c/Fish_brain.png)

The peripheral nervous system is consist of two type of nerves

1) Spinal and

2) Cranial.

Cranial nerves originated from the brain and in teleost ten pairs of them are found.

The Cranial Nerves

The olfactory nerve (I)

The optic nerve (II)

The oculomotor nerve (III)

The trochlear nerve (IV)

The trigeminal nerve (V)

The abducens (VI)

The facial nerve (VII)

The auditory (which can be called the statoacoustic or vestibulocochlear) nerve (VIII)

The glossopharyngeal nerve (IX)

The vagus (X)

OLFACTORY NERVE

The olfactory nerve (I) originates from the olfactory lobes or the front end of the cerebral hemispheres and ends in an olfactory rosette. It carries olfactory impulses from the olfactory sac to the brain.

OPTIC NERVE

The optic nerve (II) carries optic impulses from the eye. It is a thick nerve and attaches to the ventral surface of the diencephalon.

OCULOMOTOR NERVE

It arises from the ventral side of the midbrain and enters into orbit via the optic foramen. It conveys somatic motor impulses to most of the extrinsic ocular muscles, obtains proprioceptive impulses from these muscles and carries autonomic fibers to the eye.

TROCHLEAR NERVE

The trochlear nerve originates from the dorso-lateral side of the brain between the optic lobes and the cerebellum. It passes through the cranial wall and extends to the dorsal oblique muscle.

TRIGEMINAL NERVE

It is a large nerve and has three main branches 1) the profundus which obtains stimuli from the skin of the snout 2) the maxillary branch which innervates the upper jaw and 3) the mandibular branch which innervates the lower jaw. It originated from medulla oblongata.

ABDUCENS NERVE

It originated from the ventral side of the medulla oblongata. It carries somatic motor fibers to the lateral rectus and returns proprioceptive (somatic sensory) impulses from this muscle.

FACIAL NERVE

It originated from the side of the medulla oblongata behind the trigeminal. It has many branches like the hyomandibular branch.this branch is divided into pre spiracular and post spiracular branches. The post spiracular further divides into hyoidean and mandibular branches. It is the nerve of the hyoid arch, spiracle, and the cranial lateral line organs. Its superficial ophthalmic and buccal branches contribute to the superficial ophthalmic and infraorbital nerves, respectively. They return somatic sensory impulses from the lateral line canals, pit organs, and ampullae of Lorenzini.

AUDITORY NERVE

It originated from the sides of medulla oblongata. It has two branches 1) vestibular branch and saccular branch. Vestibular branch is from the utriculus and ampullae of the inner ear. Saccular branch is from the sacculus and the lagena.

GLOSSOPHARYNGEAL NERVE

The glossopharyngeal nerve originates from the ventrolateral part of the medulla oblongata behind the auditory and reaches the first gill slit. It innervates the part of the lateral line system, tongue and the pharynx.

VAGUS NERVE

It originated from glossopharyngeal. It supplies various visceral organs and the lateral line along the main part of the body. Its branches run to all the gill slits innervating the pharynx and the gill muscles.

9.4 RECEPTORS

Fish possess various types of receptors that allow them to sense and interact with their environment. These receptors play a crucial role in detecting and responding to stimuli, facilitating behaviors such as feeding, mating, avoiding predators, and navigating their surroundings. Here are some of the main types of receptors found in fish:

Visual Receptors: Fish have well-developed eyes that enable them to perceive their surroundings. Their eyes contain photoreceptor cells called cones and rods, which allow them to differentiate colors, detect light intensity, and perceive movement. Different species of fish have varying degrees of visual acuity and color vision.

Olfactory Receptors: Fish have a highly developed sense of smell. They possess olfactory receptors located in their nostrils or olfactory rosettes. These receptors detect and analyze chemical cues in the water, helping fish to locate food, identify potential mates, and navigate their environment.

Gustatory Receptors: Gustatory receptors are responsible for the sense of taste. Fish have taste buds located in their mouths and on their lips, allowing them to detect and distinguish different flavors in their food. This helps them determine the palatability of potential prey or recognize certain chemical cues.

Lateral Line System: The lateral line system is a unique sensory system found in most fish. It consists of a series of sensory organs called neuromasts, which are arranged along the sides of the fish's body and head. These organs can detect changes in water pressure and vibrations, providing fish with information about their environment, water currents, and the movement of nearby objects.

Mechanoreceptors: Mechanoreceptors are sensory receptors that respond to mechanical stimuli such as pressure, touch, and vibration. Fish possess various mechanoreceptors distributed throughout their bodies, including in their skin, fins, and sensory organs. These receptors help fish sense changes in water pressure, contact with objects, and movements of their body or surroundings.

Electroreceptors: Some species of fish, such as sharks and rays, possess specialized electroreceptive organs called ampullae of Lorenzini. These organs can detect weak electrical fields generated by other animals, including prey or potential threats. Electroreception helps fish locate prey hidden in the sand or detect the presence of other fish in murky waters.

These are just a few examples of the receptors present in fish. The specific types and sensitivity of receptors can vary among different species, depending on their ecological niche, habitat, and sensory requirements.

9.5 ANATOMY AND FUNCTION OF THE MAUTHNER NEURONS

In fish and amphibians, a pair of big and easily recognizable neurons (one for each half of the body) found in the rhombomere 4 of the hindbrain are known as Mauthner cells. They appear first in Lampreys and are found in all teleost fishes. These cells are known for a very fast escape reflex (known as C-start response). These cells are also known for their unusual use of both chemical and electrical synapses. Fish show C-start response which is a very quick startle or escape reflex. This response occurs in two phases: firstly the fish rotates its head about the center of mass towards the direction of future escape, and the body of the animal exhibits a curvature that resembles a letter C following the secondary phase in which fish is propelled forward. The time of response varies from species to species (from 10 to 20ms) for the first phage and 20 to 30 ms for the second phage.

The forward propulsion in fishes does not require contraction of the antagonistic muscle, but it is due to body stiffness and the hydrodynamic resistance of the tail. During phase 2 when an antagonistic muscular contraction does occur then the fish rotates in the opposite direction, leading a counter-turn, and a directional change. When a sudden stimulus e.g.acoustic, tactile or visual receives,it elicits a single action potential in one M-cell. Mauthner cells consist of two primary aspiny (lacking dendritic spines) dendrites that get segregated inputs from various parts of the neural system. The ventral dendrite gets signal from the optic tectum and spinal cord. The lateral dendrite gets signal from the octavolateralis systems.

Mauthner cells are also involved in behavioral patterns (where quick body bending movement is required) e.g. goldfish. These cells are stimulated during prey capture near the surface of the water because hunting at surface is dangerous hence required quick return back after hunting.

9.6 STRUCTURE AND FUNCTIONS OF THE SENSE ORGANS: EYE, VISUAL PIGMENTS AND VISION

The condition of light is different in aquatic and terrestrial environments. Water absorbs light and the amount of light available decreases with increase in depth. The absorption of light depends on the wavelength of light e.g. short wavelength like green blue absorption is more as compared to longer wavelength like red orange. Short wavelength ultraviolet light can enter deeper than visual spectra. Absorption also depends upon concentration of different solutes in water.

Structure of eye

Fish have eyes that are adapted for underwater vision. Their eyes are typically located on the sides of the head, providing a wide field of view and allowing them to detect predators and prey from multiple angles. However, some species, such as flounders, have eyes positioned on one side of the head, enabling them to camouflage against the seafloor. Fish have similar eyes like that of terrestrial vertebrates but the lenses are more spherical (slightly elliptical in some species) and unlike birds and mammals, fish adjust by moving the lens closer to or further from the retina not by changing shape of lens. In aquatic systems the difference between the refractive index of cornea and water is less so the lens does the majority of refraction. As the light passes via lens, it is transmitted through a transparent liquid medium until it reaches the retina. The retina contains photoreceptors which are present on the inner layer so light passes through layers of other neurons before reaching photoreceptors. Retinas consist of both rod cells and cone cells. The fish can have scotopic, photonic vision and most of the species have colour vision. Few fishes are able to see ultraviolet light while few are sensitive to polarized light. Few species of fishes have tapetum which is a reflective layer that bounces light which passes through the retina back through it again. This increases the sensitivity in low light conditions (nocturnal and deep sea species) by giving photons a second chance to be captured by photoreceptors. Compared to other tissues the utilization of oxygen is higher in the retina. Light enters the eye at the cornea and reaches the lens by passing through the pupil. The size of pupil is fixed in most of the fish species, but in elasmobranchs e.g. sharks and rays have a muscular iris which allows pupil diameter to be adjusted. The pupil shape varies from and may be circular to slit-like. The process by which eyes of vertebrates adjust focus on an object as it moves closer or further away is known as accommodation. Fish adjust focus by moving the lens closer or further from the retina. The muscles which change the distance of the lens from the retina are called *retractor lentis* (bony fishes) and *protractor lentis* (cartilaginous fishes).

During the rapid head movement in fishes like goldfish, flatfish and sharks a special mechanism called vestibulo-ocular reflex stabilises images. This reflex eye movement stabilises images on the retina by producing eye movements in the direction opposite to head movements, thus preserving the image on the center of the visual field.

The vision in the fish is mediated by four visual pigments that absorb various wavelengths of light. Each pigment is made from a chromophore and the transmembrane protein, known as opsin**.** The mutations in opsin molecule help some fishes to absorb UV light (≈360 nm), so they can see objects to reflect UV light. UV vision helps in foraging, communication, and mate selection. Certain fish species can detect polarized light, which is light that vibrates in a specific direction. They use this ability to navigate, orient themselves, and potentially detect prey and predators.

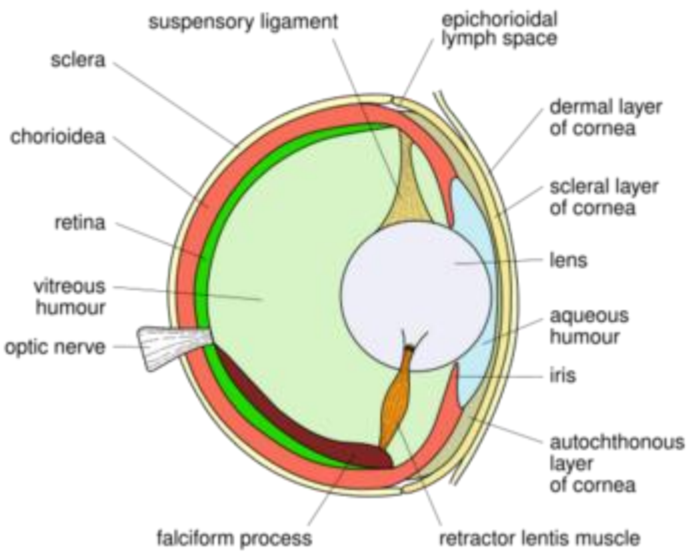

Fig 9.2 Fish eye (credit:- https://commons.wikimedia.org/wiki/File:Bony_fish_eye_multilang.svg)

9.7 CHEMORECEPTORS: OLFACTORY, GUSTATORY AND ELECTRORECEPTORS

The fish live in an aquatic environment which contains various dissolved solutes. So, fish have well developed chemoreceptors for sensing the environment. These chemoreceptors help in identifying food, locating habitat, detecting and avoiding predators, and communicating with conspecifics. Olfactory receptors help in sensing the smell (**olfaction**) to detect a broad range of chemical stimuli. And the gustatory receptors help in sensing of taste (**gustation**) to recognize food.

Olfactory Receptor

In fishes the organs responsible for recognition of smell are found within olfactory chambers. Olfactory chambers of jawed fish are paired and each of which has an incurrent and excurrent nostril. The water moved into and out of the nostril with the help of cilia within the chambers. The nostrils are small pits separated by a flap of skin. Each olfactory sac is lined with a highly folded **olfactory epithelium**, usually arranged in rosettes. Odorants molecules interact with the receptor of the receptor cells in the sensory epithelium. These receptor cells send nerve impulses to the brain. The olfactory sensitivity depends upon the structure of the rosettes and olfactory sacs. The sensitivity is directly proportional to surface area so, more extensive the lamellar folding higher the surface area. Fishes are sensitive to certain chemicals like Amino acids, bile acids, salmon gonadotropin-releasing hormone, and some sex steroids. These receptors help in

1) Homing in salmon and habitat location in few other fishes.
2) Help Sea Lamprey (*Petromyzon marinus*) to identify a suitable spawning stream and male release another pheromone to attract females
3) Help in locating mates, and some fish exhibit different olfactory sensitivities between sexes.
4) Olfaction may also be used to detect and avoid predators.

Gustatory Receptors

The gustatory receptors help in sensing of taste (gustation) to recognize food. The chemosensory cells which recognize taste are present in and around the mouth, including barbels and lips, and may also be present on the fins and trunk. The receptors for taste are generally clustered into taste buds (30-100 sensory cells) or they may occur individually on parts of some fishes. Synapsis between sensory cells and Sensory neurons occur at the basal surface of sensory cells. When stimulus molecules interact with sensory cell receptors, neurotransmitters are released that affect the generation of action potentials by the sensory neuron that transmits the signals to the brain gustatory centers. Catfish have chemoreceptors across their entire bodies and it help them to identified various things by gustation which play a important role in their orientation and food location.,

Electroreceptors

In a few fishes the lateral-line system is specialized into deeply buried, single electrically sensitive organs. Example:- In elasmobranchs like sharks and rays such organs are found on the head and are called ampullae of Lorenzini. Similar organs are found on the head of eeltail catfish (*Plotosus*), a marine bony fish (teleost). Catfish also have small pit organs known as mormyromasts. Freshwater African fish have mormyrids and electric eels have gymnotids respectively. The modification includes the withdrawal of sensory cells from the body surface, lacking kinocilia, and having no mechanical contact with the surrounding water via cupula. Ampulla and duct contain gelatinous substances that have excellent electrical conductivity.

9.8 BIOLOGICAL SIGNIFICANCE OF CHEMORECEPTION

The olfactory system in fish is highly developed and plays a crucial role in their sensory perception and behavior. Fish rely heavily on their sense of smell to navigate their environment, locate food, identify potential mates, and detect predators. Here are the key components and features of the olfactory system in fish:

Chemical Communication: Fish utilize chemical cues, known as pheromones, for communication and social interactions. Pheromones are released by fish into the surrounding water and can convey various messages related to reproduction, territory marking, alarm signals, and social hierarchy. The olfactory system in fish is highly sensitive to these pheromones, enabling them to detect and respond to these chemical signals.

Sensitivity to Waterborne Odors: Fish are capable of detecting extremely low concentrations of odorants dissolved in the water. This sensitivity is vital for their survival, as it allows them to locate food sources even in murky or low-visibility environments. Fish can detect a wide range of odorants, including those produced by prey, predators, conspecifics (members of the same species), and environmental cues. The olfactory system in fish is well-adapted to their aquatic lifestyle, where chemical cues in the water provide important sensory information. It allows fish to navigate their environment, locate suitable habitats, find food, avoid danger, and engage in social behaviors. The olfactory capabilities of fish can vary among species, depending on their ecological niche and habitat preferences. Toxins, amino acids, and bile salts are able to stimulate taste receptors at sensitivity thresholds equivalent to those of olfactory receptors. The sense of taste is used primarily for food recognition. Ampullae of Lorenzini are able to detect Earth’s electromagnetic field, and sharks use these electroreceptors for homing and migration.

9.9 ACOUSTICO-LATERALIS SYSTEM

The lateral line system is a unique sensory system found in most fish and some aquatic amphibians. It is composed of a series of sensory organs called neuromasts, which are specialized structures that detect changes in water movement and pressure. The lateral line system plays a crucial role in a fish's ability to navigate, detect prey, and avoid obstacles. This type of sense organs is distributed along definite lateral lines on the head and body of the animals. They developed from the thickening called the lateral placode in the ectoderm of the embryo. The central part of the same placode results in the development of the sensory cells of inner-ear structures (the labyrinth). Because of the common embryologic origin and structural similarities of mature neuromasts and labyrinthine cell groups, they are together known as acoustico-lateralis system.

The aquatic world is not a quiet environment but constantly the sound is generated by abiotic or biotic sources. Sound can propagate both as a pressure wave and particle displacement underwater. The sound pressures are only weakly attenuated in water. Whereas the particle displacement decreases rapidly with increasing distance from the source. Inner ear and the lateral-line of fishes both are sensitive to particle motion. Thus, close to a sound source both the hair cells in the fish ear and the lateral-line system are stimulated by the particle motion component of sound sources. In recent time acoustic noise increases due to lots of human activities in the aquatic system and it affects fishes in a variety of ways e.g. acoustic communication between fishes may be disrupted, fish may leave certain regions or habitats to avoid sound, injury or loss of life due to noise and negative affect on foraging, predator avoidance and parental care.

9.9.1 LABYRINTH

In vertebrates rotation reception is present within the labyrinth. Each labyrinth consists of three semicircular canals that align planes at right angles to each other. These canals communicate with the utriculus. These canals are widened into an ampulla at one end and the ridge (crista) of the ampullar wall contain sensory cells (hair cells) that are arranged in a row. The crista is aligned at right angles to the plane of the canal. The hairs of its sensory cells are embedded in a jellylike cupula that extends to the opposite wall of the ampulla. Endolymph displacement through a canal makes the cupula move aside. When an animal turns its head around the vertical axis to the left it increases the neural-impulse frequency (activation) in the left horizontal crista and head turn to the right causes a frequency decrease (inhibition). At the same the opposite effects occur in the right horizontal crista.

9.9.2 LATERAL LINE ORGANS

A system of tactile sense organs which help in detection of movement and pressure changes in the surrounding water is known as lateral line system (or lateralis system). This system consists of a series of mechanoreceptors called neuromasts (lateral line organs) arranged in an interconnected network along the head and body. Neuromasts may be arranged in a row or singly. Rows of neuromasts are present on the surface of the skin while in many fishes these cells lie embedded in the floor of mucus-filled structures called lateral line canals.

Neuromasts are formed from the cluster of sensory and support cells encapsulated by a jellylike sheath called the cupula. These sensory cells, or hair cells, have several small cilia, and each cilium is stimulated by water movement or pressure from a single direction. So, this system helps the fish to detect the direction and rate of water movement.and this allows fish to sense its own movement, movement of nearby predators or prey and the water displacement of stationary objects.

The various stimuli detected by this system can be generated at the water surface or in midwater. The surface disturbances can be generated by various events like insects falling in water or water organisms contacting the water air interface for feeding/ breathing. The subsurface disturbances can be produced by swimming movement of aquatic organisms. Above mentioned disturbances are biotic. Number of abiotically generated hydrodynamic stimuli e.g. wind or leaves falling onto the water are generally termed as unwanted background noise because they interfere with biologically more relevant water movements. Abiotic disturbances like currents, tides, changes in temperature and salinity gradients are generated below the water surface.

In fish neuromast sensory organs are distributed across the entire body. Neuromast are made up of macula containing sensory hair cells, supporting cells and mantle cells. Hair cells have ciliary bundles which are embedded in a gelatinous dome-like structure known as cupula. Disturbance in water results in deflections of the cupula causing shearing of the ciliary bundle. The shearing of the ciliary results in change in the hair cells' membrane potential.

The peripheral lateral-line system is divided into a population of 1) superficial neuromasts and 2) a population of canal neuromasts. Superficial neuromasts (SN) are present directly on the skin surface and arranged in lines or clusters on the head, trunk and tail fin. The function of SNs is detection of velocity. Their neuronal responses are proportional to the velocity of the water flowing around the cupula. The canal neuromasts (CN) are present in canals on fishes' heads and trunk.

The fluid present inside the canals interact with the water surrounding the fish by a series of canal pores. The function of CNs is to detect the pressure gradient. They respond to pressure differences between two adjacent canals. In bony fishes, mainly teleosts, one CN is generally present between two neighboring canal pores.

In some fishes (eg. sharks and rays) the neuromasts are modified into an electroreceptor known as ampullae of Lorenzini. In sharks these receptors are connected to the head and help in dection of minute electrical potentials produced by the muscle contractions of prey. Ampullae of Lorenzini are able to detect Earth's electromagnetic field, and sharks use these electroreceptors for homing and migration.

9.10 SUMMARY

Fish have a well-developed nervous system that allows them to perceive and respond to their environment. While their nervous system is less complex compared to mammals and birds, it is still highly specialized for their aquatic lifestyle. The nervous system of fish consists of the central nervous system (CNS) and the peripheral nervous system (PNS). Fish possess various types of receptors that allow them to sense and interact with their environment. These receptors play a crucial role in detecting and responding to stimuli, facilitating behaviors such as feeding, mating, avoiding predators, and navigating their surroundings. In fish and amphibians, a pair of big and easily recognizable neurons (one for each half of the body) found in the rhombomere 4 of the hindbrain are known as Mauthner cells. They appear first in Lampreys and are found in all teleost fishes. These cells are known for a very fast escape reflex (known as C-start response). Fish have eyes that are adapted for underwater vision. Their eyes are typically located on the sides of the head, providing a wide field of view and allowing them to detect predators and prey from multiple angles. However, some species, such as flounders, have eyes positioned on one side of the head, enabling them to camouflage against the seafloor. The fish live in an aquatic environment which contains various dissolved solutes. So, fish have well developed chemoreceptors for sensing the environment. These chemoreceptors help in identifying food, locating habitat, detecting and avoiding predators, and communicating with conspecifics. Olfactory receptors help in sensing the smell (olfaction) to detect a broad range of chemical stimuli. And the gustatory receptors help in sensing of taste (gustation) to recognize food. The lateral line system is a unique sensory system found in most fish and some aquatic amphibians. It is composed of a series of sensory organs called neuromasts, which are specialized structures that detect changes in water movement and pressure.

9.11 TERMINAL QUESTIONS AND ANSWERS

1. The electroreception in fishes is

a) Mauthner cell

b) Ampullae of Lorenzini.

c) Opsin

d) All of above

2. The lateral line system is a unique sensory system composed of

a) Chloroplast

b) Chromophore

c) Neuromasts

d) None of above

3. Mauthner cells are involved in

a) C-start response

b) Digestion

c) Respiration

d) All of above

4. Opsin is

a) Hormone

b) Chromophore and the transmembrane protein,

c) Pigment

d) None of above

Answers:- 1 (b), 2(c), 3(a) and 4(b)

5. Write a short note on

1) Mauthner neurons

2) Chemoreceptors in fishes

3) Acoustico-lateralis system

6. Write about Olfactory, gustatory and electroreceptors in fishes.

7. Describe structure and functions of the sense organs eye in fishes.

8. Write about Lateral line organs and Labyrinth.

9. Explain structure and functions of the brain and cranial nerves in fishes.

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UNIT 10: ENDOCRINE SYSTEM

Content

10.1 OBJECTIVES

After studying this unit learns will learn:

1. Hypothalamo-hypophyseal system
2. Neurosecretory system and neuro-hypophyseal hormones
3. Functional morphology of pituitary
4. Hypothalamic control of pituitary
5. Corpuscles of Stannius
6. Urophysis
7. Pineal

10.2 INTRODUCTION

The metabolic processes that occur in an organism are controlled by various systems. Endocrine system is one of the systems in an organism that controls digestion, growth, reproduction etc. This system consists of glands (known as endocrine glands) which produce hormones. These hormones control the number of physiological functions in an organism. The hormones are produced by specialized cells called glands. These glands are of two types 1) Endocrine and 2) Exocrine glands. The exocrine gland secretes hormones into a ductal system to an epithelial surface e.g. skin, Salivary Glands, stomach, pancreas, duodenum, and breasts. Whereas the endocrine glands secrete hormones directly into the circulatory system (bloodstream) e.g. hypothalamus, pituitary gland, pineal gland, thymus, pancreas, ovaries and testes. Hormone is derived from hormao (I excite or arouse). Hormone exerts their function via chemical signals which are recognized by specific receptors on the target cells. They control various processes like reproduction, growth, maintenance of the internal environment and regulation of metabolism. Hormones chemically can be protein or peptide hormones, glycoprotein hormones, steroid hormones, or amine hormones. In fishes various endocrine glands perform different tasks and functions. Various type of endocrine glands are found in the fishes e.g.- The pituitary gland or Hypophysis, Thyroid Gland Adrenal gland, Corpuscles of Stannius, Ultimobranchial Glands, Urohypophysis, Pancreatic islets and Pineal gland. Cyclostomes, elasmobranchs and osteichthyes have more complex endocrine glands. Elasmobranchs (sharks) have well developed endocrine glands but these glands have some interesting differences from those of higher chordates. But, osteichthyes (bony fishes) endocrine glands are more similar to higher chordates. The endocrine glands of fish and mammals are different due to the development and modification of various body systems in these two classes, and secondly due to demands of an aquatic mode of life.

10.3 *HYPOTHALAMO-HYPOPHYSEAL SYSTEM*

The hypothalamic neurosecretory system of the marine fish is made up of two nuclei 1) the nucleus praeopticus and 2) the nucleus laterlistuberis, which are paired. The hypothalamo-hypophysial tract extends posteriorly from each body, and they penetrate into the pituitary gland to fuse to form one structure. The pituitary gland is a master endocrine gland that originates embryologically from the two sources. The first ventral down-growth of a neural element from the diencephalon known as the infundibulum which joins with another, an ectodermal up-growth (extending as Rathke's pouch) from a primitive buccal cavity. Both of these outgrowths are ectodermal in origin and enclose mesoderm in between them, which later on supply blood to the pituitary gland, originating from the inter-renal carotid artery. This gland is placed below the diencephalon (hypothalamus), behind the optic chiasma and anterior to saccusvasculosus, and is connected to the diencephalon via stalk or infundibulum. So, the pituitary gland, which is made up of adenohypophysis and the neurohypophysis, is connected to the hypothalamus by a short stalk that have neurosecretory fibers projecting from the brain to the pituitary in fishes. The infundibulum size varies according to the species. Generally in cyclostomes it is smaller but increases in bony fishes, with prominence in groove or depression of para-sphenoid bone receiving the gland. The pituitary gland is oval shaped and is dorsoventrally compressed. The size of male glands is smaller compared to those of females.

In case of vertebrates, the hypothalamus receives various internal and external environmental signals and integrates it to regulate the pituitary (hypophysis). In teleost the hypothalamus-pituitary-gonadal (HPG) axis predominantly regulates reproduction. The posterior part of the pituitary is neurohypophysis which has a rich supply of neurosecretory fibers that release vasotocin and isotocin. It is glandular and originated from the ectoderm. The anterior part of pituitary is adenohypophysis, have various pituitary endocrine cells secreting pituitary hormones, which include FSH, LH, thyroid-stimulating hormone (TSH), growth hormone (GH), prolactin (PRL), adrenocorticotropic hormone (ACTH), and somatolactin (SL). It is a nervous part which originates from the infundibular region of the brain. Both these parts are closely associated with each other.

The pituitary gland is divided into two parts:

(a) Adenohypophysis:-. Adenohypophysis is divided into

1) Pro-adenohypophysis – Rostral pars distalis: - Present dorsal to the mesoadenohypophysis in the form of a thin strip.

2) Mesoadenohypophysis – Proximal pars distalis: - Present almost in between the rostral pars distalis and pars intermedia.

3) Metaadenohypophysis – Pars intermedia: - Present at the distal tapering end of the pituitary gland.

(b) Neurohypophysis:-. Pituitaries are broadly categorized as platybasic and leptobasic. In platybasic form e.g. Eel, the neurohypophysis contains the flat floor of the caudal infundibulum that sends processes into disc-shaped adenohypophysis. In leptobasic, the neurohypophysis has a fairly well developed infundibular stalk and the shape of adenohypophysis is globular or egg shaped.

In fish, hypothalamic hormones which regulate pituitary functions are directly transported to the respective pituitary endocrine cells by neuronal fiber projections to the adenohypophysis. Neuronal processes which are immunoreactive to various hypothalamic hormones project into the pituitary. Hypothalamic hormones are produced from the nerve terminals to act directly on nearby target cells. Teleost is a good model to study hypothalamic control of the pituitary endocrine cells because of direct innervations from the hypothalamus to the adenohypophysis and the segregation of endocrine cells in the pituitary. Unlike typical vertebrate hypothalamohypophysial portal vascular system for transport of neurohormones to pars distalis.

There is relation between the distribution of hypothalamic neuronal fibers and the endocrine target cells in the adenohypophysis of teleostse.g, fiber terminals of GnRH neurons are found in the proximal pars distalis, where LH and FSH cells are present, which justifies the role of GnRHin GtH secretion. Neurons synthesizing several neuropeptides and neurotransmitters e.g. GnRH, GABA, neuropeptide Y, dopamine, and PACAP have project their fibers to the pars distalis to modulate the release of GtH and other pituitary hormones. The brain regions contain two hypophysiotropic nuclei known as the nucleus preopticus (NPO) and the nucleus lateralistuberis (NLT), which control teleosteanadenohypophyseal functions. In most teleosts, both NPO and NLT form the major neuronal systems that innervate the pituitary to control different endocrine cells. But, some extra hypothalamic areas e.g. Olfactory system and the telencephalon have also sent neuronal projections to the pituitary. In the preoptic area (POA)-hypothalamus, the anterior and posterior subdivisions of the nucleus preopticusperiventricularis (NPP) is the regions which have various peptide hormones and neurotransmitters e.g. dopamine that control of GtH secretion in the pituitary.

10.4 *NEUROSECRETORY SYSTEM AND NEURO-HYPOPHYSEAL HORMONES*

Hormones of Adenohypophysis: Secreted by Proximal pars distalis are following

1) Thyrotrophs cells secrete Thyrotropin TSH:- It regulates the growth and secretion from thyroid

2) Gonadotrophs cell secrete Gonadotropin e.g. FSH (follicular stimulating hormone) and LH (luteinizing hormone):- It regulates secretion of gonadal hormone, spermatogenesis and oogenesis

3) Somatotrophs cells secrete Somatotropins e.g.GH (Growth hormone):- It increase growth and BMR of the fish body

Hormones of Adenohypophysis: secreted by Rostral pars distalis are following
1) Lactotrophs cells secrete Prolactin: - It regulation of osmoregulation and melanogenesis
2) Corticotroph cells secrete Corticotropin viz. ACTH:- It regulates secretion of corticotropins from adrenal gland.
Hormones of Adenohypophysis: secreted by Pars intermedia is following

1) MSH and MCH (melanophore dispersing and melanophore contracting hormone) It regulates the concentration and dispersion of pigments within melanophores. Hormones secreted by Neurohypophysis Pers- nervosa are following
1) Vasopressin and oxytocin :- It regulates osmoregulation, salt-water balance, mating and egg laying

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10.5 *FUNCTIONAL MORPHOLOGY OF PITUITARY*

The pituitary gland cells produce hormones and these hormones are stored in granules present in the cytoplasm. The cells are, therefore, classified on the basis of staining properties of granules of these cells. Cell types (secretory granules) of adenohypophysis which are stained by acidic dyes are called acidophilic and the cells which are stained by basic dyes are called basophilic.
The teleost have a unique hypo-thalamo-pituitary system amongst vertebrates, as there is direct innervation of pars distalis by neurosecretory neurons of hypothalamus
(a) Pro-Adenohypophysis: Its cells secrete prolactin and corticotropin (ACTH).

(b) The meso adenohypophysis (proximal pars distalis) cells secrete gonadotropin (GTH) and growth hormone (GH).

(c) Meta adenohypophysis: It contains neurohypophysial tissue..

Neurohypophysis:
The neurohypophysis contains connective tissue, neuroglia cells and a loosely tangled network of nerve fibers. These nerve fibers are scattered horizontally along the dorsal part of the adenohypophysis. They are generously inter-spread with granular material, large irregularly shaped amorphous masses (called Herring bodies) and large nuclei. The amorphous masses are connected to di-encephalic neuro-secretory cells called nucleus preopticusvia fibre tract (preoptic neurohypophysial tract). The diencephalon is a parts of the brain contain a group of neurons and each group is called nucleus. Hormones produced by pituitary are following

1) Gonadotropin

Gonadotropin (GTH) cells are mostly found in the proximal pars distalis (PPD), in the form of solid ventral rim of cells e.g. Cyprinoide. In salmonids and eel these cells are spread throughout rostral pars distalis (RPD). The gonadotroph (GTH) secretion is regulated by gonadotropin releasing hormone. In fishes there is only one functional gonadotropin known as piscian pituitary gonadotropin (PPG) is found. This hormone shows the same properties as LH and FSH of mammals. Salmon pituitary produce gonadotropins which resemble LH.

2) Adrenocorticotropic Hormone (ACTH). This hormone is secreted by ACTH cells located between the rostral pars distalis and the neurohypophysis. Its Secretion is regulated by hypothalamus via corticotrophin releasing factor (CRF). In teleosts, neurohypophysial peptides regulate the secretion of ACTH.

3) Prolactin

In some fishes e.gmummichog (Fundulusheteroclitus), prolactin along with the intermedin increase the production of melanin in the melanophores of the skin. Prolactin also helps in electrolytic regulation in teleosts. The production of this hormone from the teleost pituitary is under an inhibitory neuroendocrine control of hypothalamic origin.

4) Growth Hormone (GH). Meso adenohypophysis synthesis growth hormone which accelerates increase in the body length of fishes. It is seen in cultured Salmo gairdneri and Anguilla Anguilla that GH secretion may be influenced by osmotic pressure, their pituitaries release more GH in a medium containing low sodium than in a high sodium medium, relative to plasma sodium levels.

5) Melanocyte Stimulating Hormone (MSH) or Intermedin: meta-adenohypophysis secrete this hormone and its function is opposite of that of melanin hormone (MAH). MSH expands the pigment in the chromatophores, thus taking part in adjustment of background. It also regulates the synthesis of melanin. In teleost Pars intermedia of pituitary comprise two kinds of secretory cells

these cells are source of melanocyte stimulating hormone (MSH) which stimulates melanin dispersion in the melanocytes and darkening of skin.

6) Oxytocin and Vasopressin Hormones

In fish the neurohypophysis produces two hormones 1) oxytocin and 2) vasopressin; these hormones are stored in hypothalamic neurosecretory cells. In fishes these hormones regulate osmoregulation by maintaining water and salt balance.

10.6 *HYPOTHALAMIC CONTROL OF PITUITARY*

The hypothalamus has various neuropeptides and neurotransmitters that stimulate pituitary gonadotropes e.g. gonadotropin-releasing hormone (GnRH) synthesized in a specific neuronal population of the hypothalamus stimulate the synthesis and release of gonadotropins (GtHs; follicle- stimulating hormone, FSH, and luteinizing hormone, LH) in the pituitary. GnRH release and gonadotropes (FSH and LH cells) sensitivity to GnRH mainly determine the activity of the HPG axis. GtHs move throughout the body via bloodstream and stimulate maturation of the gonads (ovaries and testes) by binding to their respective receptors on them. Gonads when matured produce sex steroid hormones e.g. estrogens and androgens, which negatively regulate the hypothalamus and the pituitary (long- and short- negative feedback loops). This closed-loop system maintains the homeostasis of the reproductive system. In the reverse situation LH surge in females and the onset of puberty, sex steroids exert stimulatory effects on the hypothalamus and the pituitary (long- and short-positive feedback loops) to initiate the activation of the HPG axis.

10.7 *CORPUSCLES OF STANNIUS*

As we know, mammals regulate calcium concentration in plasma by the calcium-sensing receptor (CaSR) and PTH secretion from the parathyroid glands. Mammals obtain calcium from dietary sources, but fish obtain calcium from the surrounding aquatic environment. In fish calcium regulation is mediated by the hypocalcemic hormone, STC-1. This hormone is secreted by teleost-specific endocrine glands the corpuscles of Stannius (CS).This gland is associated with the kidneys. STC-1 maintains calcium homeostasis by inhibiting gill calcium transport, decreasing intestinal calcium uptake, and stimulating phosphate reabsorption by renal proximal tubules. Synthesis of STC-1 is sensitive to extracellular ionized calcium concentration.

10.8 *UROPHYSIS*

This gland is present only in elasmobranch and bony fishes, likely developed independently in each group. This gland is made up of neurosecretory cells concentrated at the hind end of the spinal cord where it is associated with a vascular plexus to form a neurohemal organ. It secrete a hormone known as

Urotensins, which is a peptide hormone. Four different types of Urotensins are identified and named as urotensin I, II, III and IV. All the 4 types may not be present in the same fish. But, urotensin I and II are commonly found in fish. Urotensin I is a corticotropin-releasing factor (CRF)-like fish peptide, whereas Urotensin II is a somatostatin-like fish peptide. The release of Urotensin I and II is under the control of the central nervous system. Following are the functions of urotensin hormone.

Urotensin I: It may increase the blood pressure of fish.

Urotensin II: It may be involved in the contraction of smooth muscles e.g. urinary bladder leading to increase in blood pressure and urine flow.

Urotensin III: In only Gold fish,it induces the sodium intake across the gills.

Urotensin IV: It shows similar activity as antidiuretic hormones of the pituitary gland.

10.9 *PINEAL*

This gland is located near the pituitary gland and it is a photo neuroendocrine gland. Generally in fishes this gland is absent or rudimentary in adults, but parapineal anlage usually shows some early ontogenetic development. However, a parapineal-like parietal eye of lizards has been found in at least one adult teleost. In other groups of fishes, a well-developed parapineal body is found only in non myxinoidea cyclostomes. The main hormone secreted by pineal gland is indole hormone melatonin, a hormone produced from amino acid tryptophan. Melatonin (N-acetyl-5-methoxytryptamine) biosynthesis starts with conversion of tryptophan into 5-hydroxytryptophan via tryptophan hydroxylase (TPOH) enzyme. Hydroxytryptophan is then decarboxylated by enzyme aromatic amino acid decarboxylase to produce serotonin. Converts serotonin is converted into N Acetylserotonin by Arylalkylamine N-acetyltransferase (AANAT) and then N Acetylserotonin is methylated by hydroxyindole-0-methyltransferase (HIOMT) enzyme to produce melatonin.Melatonin is generally produced during the dark because light inhibits its production. So, this gland controls the rhythmic activity in the fish. This gland conveys information to the brain by a neural pathway. The pineal organ is made up of the pineal gland and the parapineal organ. In fish the entire system e.g. the photodetector, the circadian clock and melatonin synthesizing enzymes is present in the pineal organ.Three types of cells are mainly present in the pineal gland e.g. pinealocytes (photoreceptor cells), glial (supporting) cells and second order neurons (ganglion cells).The blood vessels supply blood to all parts of the pineal gland without penetrating into the parenchyma of the gland.The pinealocytes contain photopigment so they are photosensitive and they undergo morphological changes in response to changes in photoperiod. In fish the melatonin diffuses directly into the bloodstream after synthesis. The hormone melatonin controls reproduction through pineal-hypophysis pituitary-gonadal axis. Treatment with melatonin during preparatory phase causes decrease in ovarian weight and arrested ovarian recrudescence. The gold fishes which are pinealectomized in spring and then exposed to long photoperiod conditions result in ovaries regressed and plasma gonadotropin levels were significantly depressed. The melatonin has inhibitory effect on thyroid hormone in fishes during gonadal development and maturation which is required for the sex steroidogenesis in the process of reproduction.The pineal gland regulates metabolism of carbohydrate by changing the insulin responsiveness e.g goldfish. The function of Melatonin is to control the reproductive seasonality by stimulating the final stages of sexual maturation and by synchronizing the oocyte maturity with optimal timing of spawning. It also affects estradiol levels in mature carp females and indirectly affects the secretion of GtH II byhypothalamic stimulatory (GnRH) centers.

10.10 *SUMMARY*

The metabolic processes that occur in an organism are controlled by various systems. Endocrine system is one of the systems in an organism that controls digestion, growth, reproduction etc. This system consists of glands (known as endocrine glands) which produce hormones. These hormones control the number of physiological functions in an organism. The hormones are produced by specialized cells called glands. These glands are of two types 1) Endocrine and 2) Exocrine glands. The pituitary gland, which is made up of adenohypophysis and the neurohypophysis, is connected to the hypothalamus by a short stalk that have neurosecretory fibers projecting from the brain to the pituitary in fishes. In the case of vertebrates, hypothalamus receives various internal and external environmental signals and integrates it to regulate the pituitary (hypophysis). In teleost the hypothalamus-pituitary-gonadal (HPG) axis predominantly regulates reproduction. The posterior part of the pituitary is neurohypophysis which has a rich supply of neurosecretory fibers that release vasotocin and isotocin. It is glandular and originated from the ectoderm. The anterior part of pituitary is adenohypophysis, have various pituitary endocrine cells secreting pituitary hormones, which include FSH, LH, thyroid-stimulating hormone (TSH), growth hormone (GH), prolactin (PRL), adrenocorticotropic hormone (ACTH), and somatolactin (SL). In fish calcium regulation is mediated by the hypocalcemic hormone, STC-1. This hormone is secreted by teleost-specific endocrine glands. The corpuscles of Stannius (CS). This gland is present only in elasmobranch and bony fishes, likely developed independently in each group. Urophysis gland is made up of neurosecretory cells concentrated at the hind end of the spinal cord where it is associated with a vascular plexus to form a neurohemal organ. It secrete a hormone known as Urotensins, which is a peptide hormone. Pineal gland is located near the pituitary gland and it is a photoneuroendocrine gland.

10.11 *TERMINAL QUESTIONS AND ANSWERS*

1) Hormone secreted by fish hypothalamus

a) insulin
b) GH
c) Gonadotropin-releasing hormone
d) prolactin

2) Hormone secreted by fish Pituitary gland
   a) oxytocin
   b) GH
   c) MSH
   d) All of above
3) Hormone secreted by fish Corpuscles of stannius
   a) STC-1
   b) melatonin
   c) GH
   d) Vasopressin
4) Hormone secreted by fish Urophysis gland
   a) Insulin
   b) Urotensin
   c) GSH
   d) LH
5) Hormone secreted by fish Pineal gland
   a) melatonin
   b) Urotensin
   c) GH
   d) Prolactin

Answers: 1(c), 2(d), 3(a), 4(b) and 5(a)

6) Write a short note on

a) Hypothalamo-hypophyseal system
b) Hypothalamic control of pituitary gland
c) Corpuscles of stannius
d) Urophysis
e) Pineal

7) Describe the function of various hormones secreted by the Pituitary gland.

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UNIT 11: IMMUNE SYSTEM

CONTENTS

11.1 OBJECTIVES

After studying this module, you shall be able to learn and understand:

(a) Immune system of fish

(b) Development of immune sysytem

(c) Fish immune responses

(d) Host-parasite interaction

(e) Humoral and cell mediated immune defence

11.2 INTRODUCTION

The immune system is a set of cellular and humoral components to defend the body against foreign substances, such as microorganisms, toxins or malignant cells, responding to factors such as endogenous or exogenous components that stimulate this system. The fish immune system is divided into innate and adaptive (memory), both divided into cell mediated defense and humoral factors (soluble substances), although today it is known that these two systems work together in order to destroy invaders or to trigger defense processes. The innate system includes all components present in the body before the appearance of the pathologic agent, as the first line of defense that acts faster than the specific system. Among these components there is the skin as a physical barrier, the complement system, the antimicrobial enzymes, the interleukins, the interferon and the organic defense cells, such as granulocytes, monocytes, macrophages and natural killers cells. The inflammation is also considered an innate mechanism of immune response, mediated by complex interactions of cellular and humoral compounds. Once a tissue has been penetrated by an infectious agent, mediator factors are released in order to extend and make blood capillaries more permeable, allowing the migration of the defense cells. The granulocytes are the first cell type to arrive at the inflammation focus, being responsible for the destruction of pathogens. On the other hand, the remaining pathogenic cells and cellular debris are phagocytosed by macrophages.

The innate immunity is the oldest system in the phylogenetic scale and probably originated in unicellular organisms during the evolutionary period. By definition, this system recognizes regions in molecules called Pamps - Pathogen Associated Molecular Patterns - from infectious agents or microorganisms of normal microbiota, such as lipopolysaccharide, peptidoglycan, bacterial DNA or viral RNA, or other molecules found in multicellular organisms membranes known as “non-self”. The Pamps are usually highly preserved portions during the evolution of species and are found in the greater part of microorganisms. Conversely, the specific system first appeared around 450 million years ago, and can be found in all vertebrates except in fish of the Agnatha class. The acquired system receptors are responsible for detecting the pathogenic agent, and can be found in the cell membrane of T lymphocytes (TCR - T cell receptor) and B lymphocytes (BCR - B cell receptor, also called as well as membrane immunoglobulin) or in serum as free antibody.

The specific system of defense requires the presence of an antigen, which is a strange molecule or cell that will initiate reactions and culminate in the increase of circulation of specific antibodies, besides promoting immune memory. Antigens that enter the body will be recognized and processed by the innate system by antigen presenting cells (APC - macrophages, dendritic cells and B lymphocytes), to process microorganisms in molecular units, and at first trigger immune response of proliferation, and in a second moment, the response of memory. As a result, the antigen processed by APC will be presented to the T lymphocytes which are the cells of the specific system. T lymphocytes carry the ability to recognize the antigen strictly in the presence of a specific humoral component called major histocompatibility complex molecules, which are glycoprotein receptors coded by genes in a major histocompatibility complex (MHC). After this recognition, the T cell secretes cytokines, which are proteins that activate other cells such as B lymphocytes (responsible for the production of antibodies), cytotoxic lymphocytes, macrophages and other cells in order to destroy the invading agent.

The antibodies recognize and connect to specific microorganisms and consequently activate phagocytosis (component of the innate system, indicating that the specific and innate systems act together). Antibodies may promote agent neutralization or opsonization and may bind to extracellular antigens in addition to complement system. However, if the antigen is established in the intracellular compartment the defense is conducted by cytotoxic T lymphocytes. The adaptive response of fish is commonly delayed but is essential for long-lasting immunity and is a key factor in successful vaccination.

11.3 DEVELOPMENT OF IMMUNE SYSTEM

As per the cellular organization and physiologic requirement there are variations in pattern of immune system ontogeny in different group of fishes. There are many similarities between fish and human immune system but unlike human they have a resilient innate immunity which helps them to survive and adopt to the adverse condition inside water. Fishes do not have bone marrow and lymph nodes but head kidney plays a major role in hematopoiesis as well as direct antimicrobial activity through melanomacrophage centers (MMC). Apart from anterior and middle kidney, thymus and spleen are two important lymphoid organs present in fish. The development pattern of fish lymphoid organs is variable according to the type of fish.

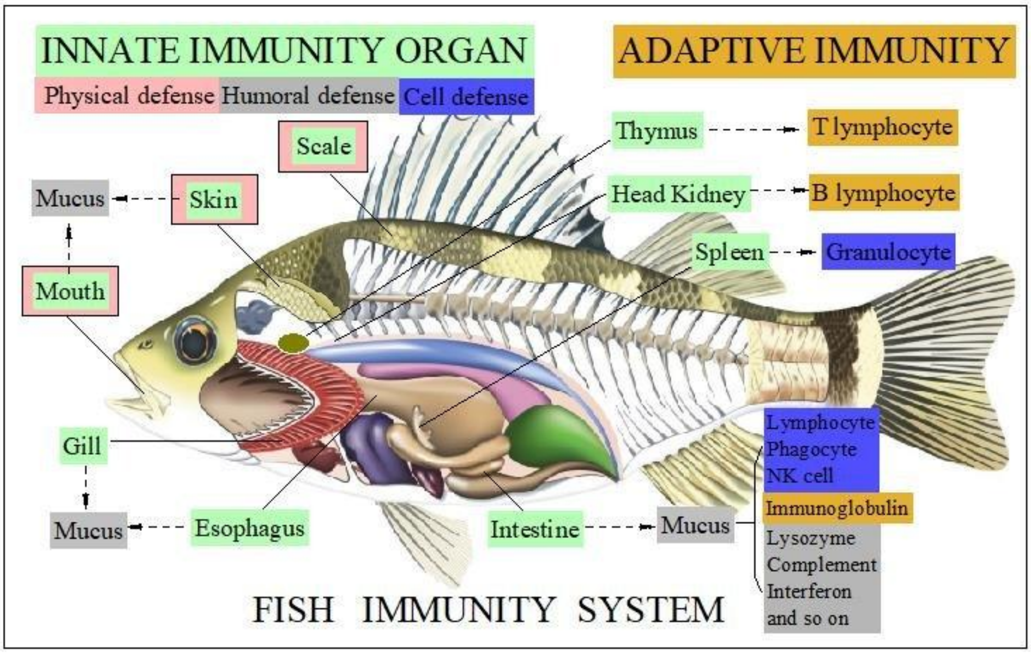

Fig.11.1: Basic Concept of Fish immune System

The kidney (head and middle), thymus and spleen are the largest lymphoid organ in teleost fishes. The development sequence of lymphoid organ varies between freshwater and marine water fish species. In case of freshwater teleost e. g. carp, tilapia and trout, kidney is the first lymphoid organ to develop and spleen is the last organ. Lymphoid organs of marine fish develop differently in order of kidney, spleen and thymus respectively. In marine water teleost fishes, such as cobia (*Rachycentron canadum*), Flounder (*Paralichthyus olivaceaus*), Sea bream (*Sparus aurata*), yellow tail (*Seriola deumerili*) and red sea bream (*Pagrus major*) the anterior kidney is the first lymphoid organ to appear followed by spleen and thymus. But in both cases thymus is the first organ to have lymphoid cells followed by kidney and spleen.

1. Kidney: In teleost fish, kidney functions similar to bone marrow in the vertebrates and is the largest site of hematopoiesis. Immune cells are present over entire kidney whereas anterior or head kidney has the highest concentration of developing B-lymphoid cells. The anterior kidney is aglomerular and has hematopoietic function and unlike higher vertebrates, it is principal organ for phagocytosis, antigen processing, formation of IgM and immune memory through melanomacrophage centres. In fish, the head kidney serves as an important endocrine organ, homologs to adrenal gland in mammals and release corticosteroids and other hormones. Furthermore, anterior kidney is the major site for antibody production.

Anterior/head kidney is the initial common site for hematopoietic stem cells (HSC) development and differentiation. At early hatching condition rudimentary pronephric kidney use to carry undifferentiated precursor cells even in the absence of any blood islands which are believed to be the first site of pluripotent stem cell formation in mammalian yolk sac. Comparison with human immune system reveals that after migration of precursor cells from fetal liver and spleen, pro-myeloid cell formation occurs in bone marrow for life time and this is why anterior kidney of fish is similar in action to bone marrow of higher vertebrates.

In zebrafish a well-developed kidney can be found at 72 hours post fertilization (hpf) but hematopoietic cells appear at 96hpf. However this timeframe for appearance of hematopoietic cells may be different in different fishes. By gradual differentiation immature precursor cells form cords, an aggregated form of more differentiated HSCs surrounded by blood vessels. These sinusoidal blood vessels are lined by fibroblastic reticular cells. Further development from pronephric to mesonephric kidney supports for the formation of erythroblast, myeloblast and lymphoblast.

2. Thymus: The lymphoid cells which are actually major immune blood cells initially are not differentiated in the head kidney. Thymus is the most important lymphoid organ which is found in all vertebrates including chondrichthyes and the osteichthyes but an exception in case of Lamprey and Hagfish which are known to be the primitive vertebrates. However, research for the presence of thymic analogue in lamprey has revealed Thy-1 reactivity which is mainly associated with thymus and Tcell development, has been captured in different tissues including typhlosole, opisthonephros, liver, external gill openings in larval lamprey. Unlike mammals where thymus appears to carry and develop precursor cells migrated from bone marrow for T cells formation, in fish thymus is the first organ to be lymphoid. Thymus is present near gill arch and is closely associated with the pharyngeal epithelium internally facing towards head kidney. In zebrafish thymus appear as primordial outgrowth of pharyngeal epithelium at 54 hours post fertilization (hpf) and a developed thymus carry electro-lucent epithelial cells and mature lymphocytes. The morphology of thymus varies in age dependent manner from species to species and within species. In carps, thymus alters from triangular to irregular shape and even the cortex as well as medulla changes their position. The distinct cortico-medullary junction is not present in all fish. The recombination activating genes (rag), which are responsible for rearrangement of immunoglobulin gene and T-cell receptor genes in immature B and T lymphocyte respectively are often used for histological localization of premature thymus. In zebra fish, the rag1 gene expression at 92hpf distinguishes rag1+ cortex and rag1- medulla of thymus. Before this period ikaros gene which is responsible for lymphocyte differentiation is expressed in thymus at 72hpf.

Thymus of teleost is a bilobed homogenous organ placed in a dorsal projection in the epithelium of the operculum cavity and it is lined by mucus tissue of pharyngeal epithelium in structure that surrounds the lymphoid bark tissue is the characteristic of the fish thymus. Thymus in the fishes has frequent record of variation in morphology due to the absence of cortico-medullary junction. So, in many species it is not possible to differentiate between cortex and medulla that is found in higher vertebrates. The involution of thymus in fish is more dependent on hormonal cycles and seasonal variations than on the age. Teleost's thymus is much similar to mammalian in which erythrocytes, neutrophils and granulocytes are found in spleen whereas lymphocytes are major cell type found in thymus. Thymus produces T lymphocytes involved in stimulation of phagocytosis, allograft rejection and antibody production by B cells.

3. Spleen: In teleost, spleen functions as major secondary immune organ, plays major role in the clearance of blood borne antigens and immune complexes in splenic ellipsoids and in the antigen presentation and initiation of adaptive immune response. The size of spleen in fish is widely used as simple measurable immune parameter with potential role in immune response against parasite infections. Spleen is the third important hematopoietic organ which originates in form of mesenchymal cell aggregate surrounded by blood capillaries. It is the third organ to be lymphoid but for a long time it carries erythroid cells only. The expression of Hox11 transcript factor which helps in survival of precursor splenic cells indicates splenic primordium appears during 5 dpf at left anterior gut portion of zebra fish, whereas it in rainbow trout it is found at 3dph (days post hatch). The ellipsoids which are involved in plasma filtration and blood borne antigen trapping, appears at 3 months after hatching of zebrafish. These ellipsoids have narrow lumen which runs through reticular cells and macrophages.

4. Other Tissues: Apart from the major hematopoietic organ, there are additional lymphoid tissues in different organs of fish. Expression of Ikaros, which is a gene specific for lymphoid cell differentiation, is marked to be present in bilateral patches of brain at 24–96 hpf, heart, intestine and testes. Fish do not have typical lymphocyte accumulation site which is so called Peyer's patches (PP) in mammals but few macrophage-like cells and leukocytes are found in gut. However, mucosa-associated lymphoid tissue (MALT) of fish can be found in different forms like gut associated lymphoid tissue (GALT), Gill associated lymphoid tissue (GIALT), Skin associated lymphoid tissue (SALT), nasal-associated lymphoid tissue (NALT), and the recently discovered buccal and pharyngeal MALTs. GALT is known to carry immunoglobulin expressing cells such as T and B cells in intraepithelial lymphocyte and lamina propria respectively. A maximum number of intraepithelial leukocytes are found in proximal and distal gut portion but their distribution and concentration vary according to species, diet, temperature and other external influence. In teleost hind gut carries most of the Ig positive lymphocytes and the macrophages associated with gut looks different comparison to kidney and spleen macrophage. These differential immune cells are found at 14 dph in *0reochromis.mossambicus* (Tilapia) and get fully matured during 7 weeks which is quite earlier in comparison to GALT maturation in *Burbus conchonius* (during 20 weeks). Such gut lymphoid cells can be seen during 8dpf in zebrafish whereas in rainbow trout are found in gut epithelial region during 13 dph. Occasionally at the age of 54dpf few lymphocytes like cells are found in gut and skin of sea bream which is a marine fish. Unlike the mammals' fish like Rainbow trout secretes IgM, IgT/IgZ and channel catfish secrets IgD in mucus. This MALT associated Igs specific transcript expression can be detected at 4dpf in whole carp embryo but developed IgM and IgZ are found later during 4–6 weeks post-fertilization.

FISH INNATE IMMUNITY

Non-specific immunity found in all living organisms and is the first line of defense against all pathogens, also plays an important role in the activation of adaptive immune response. The cells of the innate system recognize and respond to pathogens in a generic way. It also possesses memory as the host evolves its innate immune components based on evolutionary experience of its ancestors encountering similar pathogens. Innate immunity is commonly divided into three compartments: surface barrier, humoral factors and cellular factors. As the first line of defense, it is not surprising that the majority of the broad-spectrum parameters of innate immunity are highly conserved across species and taxa. In all jawed vertebrates, the innate immune system features a rapid defensive response towards invading pathogens and tissue damage. However, it cannot provide well-directed, specific protection from individual pathogens or long-term immunological memory.

Surface Barrier: Mucus, skin, gills and gastrointestinal (GI) tract acts as first line of barrier to any infection. Layer of mucus present in skin, gills and GI tract entraps microorganisms by continuously sloughing and inhibits colonization. Mucus of fish is toxic to certain microorganism due to presence of some humoral factors. The rate of mucus production increases in response to infection or by physical or chemical irritants. The epidermis of fish skin is composed of non-keratinized living cells and the integrity of these cells plays vital role in maintaining osmotic balance and excluding microorganisms. Rapid healing is also observed in epidermis of fishes.Large surface area of delicate gill epithelium considered as important route of pathogen entry. The gills are protected by mucus production and highly responsive epithelium resulting in hyperplasia, frequently seen in various gill infections. Phagocytic cells line the branchial capillaries, lymphoid cells on the caudal edge of the intrabranchial septum. GI tract is lined by mucus membrane and also the digestive enzymes, bile and low pH of stomach provides an extremely hostile environment for pathogens.

Humoral Factors: There is array of soluble substances which have protective function which inhibits the growth of microorganisms and neutralizes the enzymes on which pathogen depends. The classification of humoral parameters is commonly based on their pattern recognition specificities or effector functions.

Growth Inhibitors: Growth inhibitors acts either by depriving microorganism of essential nutrients or by interfering with their metabolism. Transferrin occurs in serum, exerts a bacteriostatic and fungistatic effect. Transferrin is a protein with high Iron (Fe) binding capacity, which is an essential element for growth of microorganism and deprives them of iron. Pathogenic bacteria may produce their own chelating agents like siderophores to overcome this defense mechanism and hyperferremic activity acting as a counter response has been demonstrated in some fish species. Transferrin is also an acute phase protein invoked during an inflammatory response to remove iron from damaged tissue and an activator of fish macrophages. Interferons are another virus inducible cytokine which induces the expression of Mx and other antiviral proteins. Grinde (1989) studied the antibacterial effect of two lysozyme variants (Types I and II), purified from the head kidney of rainbow trout, on seven Gram-negative bacterial fish pathogens. INFα and β are cytokines with a nonspecific antiviral function that is based on the inhibition of nucleic acid replication within infected cells. Interferons are potent activator of downstream antiviral defenses and the type I Interferons (IFN-α and β) induces expression of wide range of Interferon stimulated genes (ISG) inducing Mx, Viperin, ISG 15, PKR leading to enhanced antiviral state. Type II interferons (IFN- γ) promotes Th 1 cell responses produced primarily by CD4 + Th 1 cells and NK cells. Th 1 cell provide defense against intracellular pathogens such as viruses and bacteria by inducing apoptosis restricting cell proliferation during viral infection. Fish IFN also modulates cytokines and chemokines expression and is potent inducer of proinflammatory cytokines such as IL-1, IL-6, IL-12 and tumor necrosis factor (TNF).

Enzyme Inhibitors: Pathogens produce enzymes in order to penetrate and obtain nutrients from their hosts. Tissue fluids and serum of vertebrates contains many enzyme inhibitors which are thought to defend body against autodigestion and also plays an important role in neutralizing enzymes produced by pathogens. Fish plasma contains a number of protease inhibitors, principally α1-antiproteinase and α2-macroglobulin (α2M). Many bacteria produce proteolytic toxins which digest host tissue proteins as a source of amino acids. An important protease produced by A. salmonicida is resistant to rainbow trout α1-antiproteinase but is inhibited by α2M. The difference in α2M activity between two different trout species (rainbow trout and brook trout) has been found to correlate with their resistance to A. salmonicida infection suggesting that α2M may play a role in defense against furunculosis.

Lysins: Various lytic enzymes either in single or in combination may cause lysis of pathogenic cells. Lysins in fishes include complement, lysozyme and antimicrobial peptides. Lysozyme is the most studied innate response in fish which act on the peptidoglycan layer of bacterial cell walls resulting in the lysis of bacteria. Lysozymes synthesized both in liver and extra hepatic sites and are present in mucus, lymphoid tissue, plasma as well as in other fluids and is also expressed in a wide variety of tissues and involved in a comprehensive defense mechanism, such as bacteriolysis, opsonization, as well as restricted antiviral and antineoplastic activity, as found in higher vertebrates.

Studies of the integument and integument secretions of fish have demonstrated an important role of antimicrobial peptides in host defense against viruses and bacteria. These peptides are found in mucus, gills and liver tissue of teleost fishes and include liver expressed antimicrobial peptides (LEAP), Defensins, Piscidins, and Cathelicidin.

Complement system is the biochemical cascade that helps or complements the ability of antibiotics to clear pathogens from the host. Complement system plays major role in the link between both innate and adaptive immune responses that allows an integrated host defense to pathogenic challenges. Complement system plays multiple functions like mediating inflammatory vasodilation, lysis of bacterial cells and infected cells, opsonization to foreign particles to enhance phagocytosis, clearance of apoptotic cells and also in alternation of molecular structure of viruses. The bactericidal activity of complement has been reported in many fishes. Complement system gets activated by three pathways- the classical pathway, which is triggered by antibody binding to the cell surface, the alternative pathway, which is independent of antibodies and is activated directly by foreign microorganisms, and the lectin pathway, which is activated by the binding of a protein complex consisting of mannose/mannan-binding lectin in bacterial cells.

Agglutinins and Precipitins: Mucosal or serum agglutinins and precipitins are lectins like C-type lectins and pentraxins. The C-type lectins have binding capacity for different carbohydrates like mannose, N-acetyl glucosamine or fucose in the presence of Ca ions, and the interaction between carbohydrate binding protein and carbohydrate leads to opsonization, phagocytosis and activation of the complement system . Mannose binding lections (MBL) are the most studied lections which show specificity for mannose, N-acetyl glucosamine, fructose and glucose. Lections, with various carbohydrate specificities, have been isolated from the serum of several fish species. Pentraxins (C-reactive protein, CRP and serum amyloid protein, SAP) are lectins, which are present in the body fluids of both invertebrates and vertebrates and are commonly associated with the acute phase response. Pentraxins are pattern recognition proteins that are important component of acute phase response to infection or injury. Some best known pentraxins are C-reactive protein (CRP) which is known to bind with phosphoryl choline present on many microbial cell wall and Serum amyloid protein (SAP) binds to phosphoethanolamine, glycans and also known to bind LPS of Gram-negative bacteria.

Cellular Factors: The cellular components of the fish's innate immune system consist of many different types of cells such as monocytes/macrophages, granulocytes as mast cells/eosinophilic granule cells, and neutrophils, dendritic cells, and natural killer cells (NK cells). When an innate immune cell encounters and recognizes a pathogen through its pathogen-associated molecular pattern (PAMP), the immune cells get activated and can participate in several responses depending on their cell subtype, including phagocytosis and subsequent destruction of pathogens.

Macrophages/Monocytes: Macrophages are the first cells to arrive and respond to the site of infection. Macrophages are derived from hematopoietic progenitor cells (immature cells), which differentiate through circulating monocytes or via tissue-resident macrophages namely kuffer cells in liver, glial cells in brain, etc. Macrophage differentiation is controlled by engagement of the colony-stimulating factor 1 receptor (CSF1R) first identified in the elephant shark (*Callorhinchus milii*) genome. Macrophages in teleost play a role in both the innate and adaptive immune systems and are vital players during inflammation and pathogen infection. In the innate immune system, macrophages destroy pathogens through phagocytosis, reactive oxygen species (ROS) and nitric oxide (NO) production, and the release of several inflammatory cytokines and chemokines, similar to mammalian macrophages. Similar to mammals, teleost fish also have functionally distinct macrophages. In teleost fish species, M1 (classically activated macrophages) are characterized by the production of pro-inflammatory cytokines such as TNFa and IL-1b and production of ROS and NO, and these cells may rapidly kill pathogens by engulfment and production of toxic reactive intermediates, phagolysosomal acidification, and restriction of nutrient availability. Whereas M2 are alternatively activated macrophages and are mainly associated with immunosuppression, trauma, and anti-inflammatory cytokines such as interleukin (IL)-10.

Phagocytic B Cells: Phagocytosis mediates the primary action of the teleost immune system, is the central effector mechanism of innate immunity, and also plays an essential role in linking the innate and adaptive immune responses in vertebrates. Phagocytosis is an endocytic process of phagocytes by which other cells or particles, including microbial pathogens, are ingested or engulfed to form phagosomes and phagolysosomes, followed by the destruction of the invader or the continued processing of antigenic information, eventually initiating adaptive immunity in vertebrates. Classical phagocytosis is mainly versed by "professional" phagocytes, like macrophages/monocytes, neutrophils, and dendritic cells. Moreover, some "amateur" phagocytes such as epithelial cells and fibroblasts can also internalize antigens particulate to a much lower degree compared to professional phagocytic cells. It is very well known that B cells in all vertebrates are functional antibody-secreting cells (ASCs) for producing specific antibodies in response to certain invading foreign antigens and those them play vital roles in adaptive immunity. It was a long-held paradigm that B cells are non-phagocytic cells, even though evidence has been reported that CD5+ B-cell lymphoma could differentiate to macrophage-like cells. In 2006, for the first time, it was reported that B cells derived from teleost fish and frog are competent of phagocytic and bactericidal activity through the formation of phagolysosome, which was previously only identified in professional phagocytes. Moreover, teleost fish, this novel phagocytic capability of B cells has also been notified into other vertebrates like reptiles, mice, and humans. IgM+ B cell is the most abundant immunoglobulin present in the serum of teleost fish and was first reported in rainbow trout (Oncorhynchus mykiss) and catfish (Ictalurus punctatus) for their characteristic phagocytic and bacteria-killing abilities. In the subsequent study, in rainbow trout the IgM−/IgT+ B-cell subset, which uniquely secretes IgT, gets identified, capable of phagocytic and microbicidal activity. In recent years, the phagocytic B cells of teleost fish have been identified from about ten teleost fishes but were only focused on IgM+ B-cell subsets due to the deficiency of specific mAbs against IgT or IgD in these fish species. The phagocytic activity of IgM+ and IgT+ B cells could be significantly increased after incubation with antiserum or complement-opsonized target particles. The regulatory mechanisms of interleukin IL-6 and IL- 10 are recognized in the phagocytic activity of teleost IgM+ B cells, where IL-10 could enhance the phagocytosis of IgM+ B cells in flounder. A number of B Cell receptor (BCR) like mIgM, CD79a, CD79b , and other cell receptors, such as Toll-like receptors (TLRs), Retinoic acid-inducible gene (RIG)-I-like receptors (RLRs) and NOD-like receptors (NLRs), which are common pattern recognition receptors (PRRs) of professional phagocytic cells, may also be involved in B-cell phagocytosis. The concurrence of complement and phagocytic B cells indicates the essential importance of B cells in the linkage of innate and adaptive immunity. The highly variable phagocytic abilities for the IgM+ B cells to ingest different microbial particles were also reported in zebrafish (*Danio rerio*), lumpfish (*Cyclopterus lumpus L.*), half-smooth tongue sole (*Cynoglossus semilaevis*), large yellow croaker (*Larimichthys crocea*), and Japanese flounder (*Paralichthys olivaceus*).

NK Cells: Non-specific cytotoxic (NCC) cells are akin to mammalian natural killer (NK) cells, but they do not contain cytoplasmic granules like NK cells and having pleomorphic clefted nucleus with little cytoplasm with different killing mechanism. They share several similarities, mainly the competent lytic cycle, the target cells for lysis, recognition of target cell, and the effecters to lyse the infectious microorganisms. Cells with NCC activity are primarily present in the blood, lymphoid tissues, and the gut. NCC needs to physically contact target cells without membrane fusions or fragmentation. The smallest leucocyte NCC targets various cells, including tumor cells, transformed cells, virus-transformed cells, and protozoa parasites. The killing is spontaneous, non-specific, and does not require any apparent induction period. NCCs are reported to be most active in the head kidney of teleosts, but spleen and peripheral blood leukocytes (PBL) also demonstrate cytolytic abilities. The NCC activities are influenced by age, strain; temperature, stress, and activity are more pronounced when specific responses are less active.

Stromal Cells: Stromal cells are connective tissue cells of organs that act in a supportive capacity to the parenchymal cells performing specific organ functions. During the last decade, when the complexity and function of stromal cells were revealed in immune functions, the stromal cells were considered "non-hematopoietic immune cells" before that it was merely known for providing a structural framework upon which hematopoietic immune cells could function. The growing evidence suggests that non-hematopoietic stromal cells exhibit a capacity for diverse cell intrinsic and extrinsic immune function in many non-lymphoid tissues, including the intestine, where it plays multiple immune responses inflammation at this mucosal site. Intestinal stromal cells are non-professional immune cells that recognize bacteria and other cells via TLR or NLR and modulate T-cell function. Stromal cells have various mechanisms to directly sense bacterial contact, respond rapidly on contact with pathogen proving protective immune response, and respond to cytokine signals from the epithelium and thus amplify both protective and potential deleterious immune responses.

Red Blood Cells: Unlike mammalian cells, fish red blood cells are nucleated and contain organelles in their cytoplasm. The nucleated fish red blood cells are well known for gaseous exchange but recently their new biological role in immune response has been reported. Nucleated red blood cells (RBCs) of fish contain the transcriptional and translational machinery necessary to produce characteristic molecules of the immune system to respond against various infectious agents and play an active role in maintaining homeostasis of the fish immune system. The nucleated RBC are reportedly involved in both innate and adaptive immune responses in fish. Nucleated RBCs are able to phagocytose, acts as antigen-presenting cells, recognizes pathogen associated molecular pattern (PAMPs) by specific pathogen recognition receptors (PRRs), modulate leukocyte activity, release cytokine-like factors and also induces interferon in fish. The expression of immune-relevant genes in RBC had shown a wide repertoire of TLRs in *Salmo salar* and *Oncorhynchus mykiss*, which allow them to respond to both bacterial and viral infections.

Intestinal Cells: The gastrointestinal tract cells function in digestion and maintain immune homeostasis to protect the body from potentially harmful microbes and induce a tolerogenic response to innocuous food, commensals, and self-antigens. Fish have local mucosal defense in the gut to sample antigens and produce local immunoglobulin responses. Leucocytes are abundantly present in the fish gut's lamina propria and intestinal epithelium. The indication of specific antibody secretion in the fish intestine comes after intestinal or immersion immunization of various fish species, which were rarely detectable after systemic immunization. Immunoglobulins (Ig) produced in the intestine are a result of local synthesis was get confirmed after intravenous administration of radiolabeled Ig, which never reached the mucosal secretions. Ig isotype (IgT) is specialized for mucosal immunity, and in trout fish, the IgT response to a gut parasite is restricted to the intestine. The Polymeric immunoglobulin receptor (pIgR), an essential component of mammalian mucosal immunity, has also been described in few fish species. Ig + B cells and Ig-T cells are abundantly present in fish's gut, but limited data is available regarding their functional relevance. The fish intestine, especially the posterior segment, is immunologically active and armored with various immune cell types, including B cells, macrophages, granulocytes, and T cells.

Fish Gill: Diseases associated with gill damage, cause substantial losses in the aquaculture industry not only through an increased mortality rate among fish but also through impaired growth and also by increased treatment and sanitation cost. Damage to gill tissues is specially characterized by inflammation and increased epithelial cells hyperplasia or hypertrophy. A gill epithelium of salmonids has higher number of MHC class II positive cells whereas low number of macrophages like cells has been detected in gill epithelium of presumably healthy salmonid fish.

11.4 CELL AND TISSUES OF IMMUNE SYSTEM

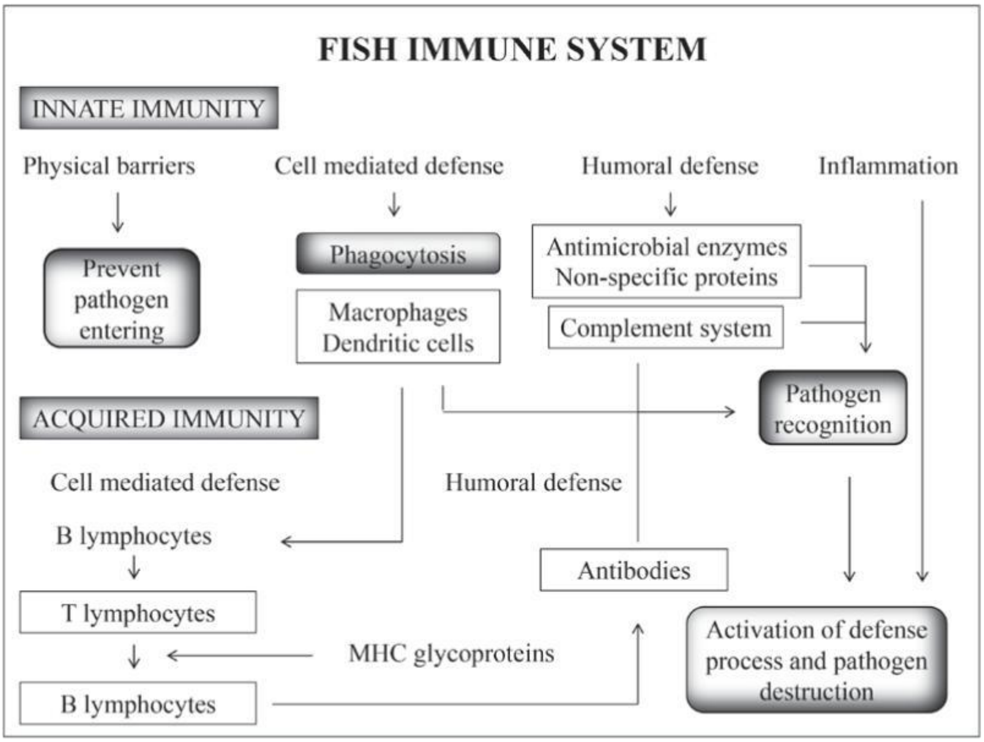

Fig.11.2: Fish Immune System

The tissues and organs that structure the immune system of bony fish are classified as lymphoid, and there is no myeloid classification, such as in mammals, because fish lack bone marrow and lymph nodes. The lymphoid organs are the kidneys (the largest lymphoid organ), thymus, spleen and gut associated lymphoid tissues (GALT), formed during larval development. It is known that there are approximately 24,000 fish species thus morphological differences have been found. The lymphoid tissues and organs are usually arranged by reticular cell networks in order to build a structure for the cells of the innate and specific defense, such as lymphocytes, monocytes, macrophages, granulocytes and thrombocytes, mast cells, NK cells, cytotoxic cells and dendritic cells. This arrangement is responsible for the production of the immune system components.

(a) Thymus: Thymus is a double organ located behind the operculum in the dorsolateral position of gills. The thymus ontogeny and histology differ according to species, however, in general, their origin occurs 24 hours after fertilization. It is considered an important tissue of T lymphocytes development and maturation. Although the involution of the thymus occurs in adult vertebrates, it can differ in bony fish depending on the species.

(b) Kidneys: The kidney is very important for fish hematopoiesis and immunity, and could even be compared to the marrow of mammals. It has the function of formation and maturation of red and white blood cells. The kidney displays differences between the anterior and posterior section, both with haemopoietic function. However, the first portion of the organ is more important for the production of defense cells, in addition to differentiation and maturation of leukocytes, including B lymphocytes, monocytes, macrophages and granulocytes.

(C) Spleen: The fish spleen contains a white pulp that promotes haematopoiesis with formation of defense cells, and a red pulp that causes phagocytosis of old or defective cells. However, different from mammals, this division in fish is not organized, although it is possible to identify each pulp in various species. The organ concentrates lymphocytes and macrophages, most of which are macrophages arranged in centers that are responsible for phagocytosis that will culminate in immune memory. Once blood flows through spleen, antigens are kept in these centers in order to be processed and presented for T lymphocytes.

(d) GALT: GALT includes gastrointestinal mucosa, gills, and skin. These tissues produce mucus containing soluble defense components, such as lysozyme, complement system proteins and immunoglobulins in order to promote the first barrier against pathogen agent. These lymphoid tissues are scattered throughout the mucosa in clusters of defense cells, including macrophages, lymphocytes, mast cells and granulocytes. These cells capture the antigen in order to process and promote immune memory. The liver has the same function as in mammals, of producing humoral compounds such as proteins of the complement system and acute phase proteins of the inflammatory response.

11.5 FISH IMMUNE RESPONSE MODULATION

Immune system modulation, also called immunomodulation, is the process that involves the use of therapy to modify the immune response, often to prevent tissue damage resulting from an excessive response. Immune system modulators are a type of immunotherapy that enhances the body's immune response against cancer. Fishes are the first group of organisms that present an innate and adaptive immunity system. The innate immune system is of paramount importance in fishes; among the components of humoral innate immunity that are mainly characterized in fishes are antibacterial peptides, lysozymes, lectins, acute-phase proteins, and molecules of the complement system, while innate immunity cells mostly characterized are macrophages, neutrophils, and eosinophils.

On the other hand, adaptive immunity mechanisms in fishes play a vital role in the protection against recurrent infections, response that is mediated by T- and B-lymphocytes and antibodies. Fishes are the first vertebrates where clonal selection and genetic rearrangement in receptors of lymphocytes are present. Likewise, leucocytes with T cell activity have been reported, similar to the cooperative and cytotoxic T cells of mammals (CD4+-like, CD8+-like). Apart from that, based on the profile of cytokines, there have been reports of T cells subpopulations similar to the ones reported in mammals. In contrast, B cells in fishes have been characterized through the expression of antigen receptor (BCR). In fishes, IgM is the main soluble antibody, which is tetrameric; on the other hand, IgD, just like in mammals, is expressed in the surface of B cells. In addition, other isotypes have been identified, such as lgT and lgZ, which are mainly found in mucosa, such as in intestine, in skin, and in gills.

Immune-neuroendocrine interactions in fish, as in mammals, have become a focus of considerable interest, with the modulation of immune responses by hormones receiving particular attention. Cortisol, growth hormone (GH), prolactin (PRL), reproductive hormones, melanin-concentrating hormone (MCH) and proopiomelanocortin (POMC)-derived peptides have all been shown to influence immune functions in a number of fish species. Exposure to various waterborne contaminants induces altered immune function in fish. Less is known about the immune response during periods of recovery subsequent to chemical exposure. Understanding such immune responses is important when monitoring fish health following exposure to fluctuating concentrations of contaminants in aquatic environments. Immune response is modulated by different substances that are present in the environment, like pollutant, pesticides etc.

11.6 HUMORAL AND CELL MEDIATED IMMUNE DEFENCE

The fish immune system is responsible for destroying microorganisms through acquired and innate components, with humoral and cellular process that perform together in an attempt to prevent the outbreak of diseases. The humoral innate system functions through several soluble components in body fluids, while the humoral specific system acts only through antibodies. Fish are susceptible to viral, bacterial, fungal and parasite agents, however, they can resist microbial invasion because of specific and innate mechanisms. The unspecific mechanisms includes the production of numerous antibacterial compounds, proteins of inflammation acute phase, complement activated by alternative pathway, cytokines, phagocytosis and inflammation.

The bony fish defense cells are produced by lymphoid tissues such as kidney, thymus, spleen and GALT since they have the same cellular precursor called pluripotent cell. The lymphoid cells production is recognized as hematopoiesis that results in the formation and differentiation of a large quantity of cell types such as erythrocytes, granulocytes, monocytes, lymphocytes, mast cells and thrombocytes. The hematopoiesis is regulated by cytokines that act on pluripotent cell receptors controlling their survival, proliferation, differentiation, maturation and function. The hematological parameters assessment can be an indicator of physical condition and diseases outbreak of the fish.

Among the defense cells of fish, thrombocytes have phagocytosis capacity besides coagulation function. They have acid phosphatase what leads the cell to be in inflammatory site. Monocytes show phagocytosis and unspecific citotoxic activities and are considered transitory cells in blood because during the inflammatory process they migrate through the connective tissue and turn into macrophages. Neutrophils are polymorphonuclear cells found in the blood, lymphoid tissues and peritoneal cavity that can phagocytosis foreign particles or cells and produce superoxide anions that are a bactericidal compound. Eosinophils are distributed by connective tissue, especially in the gastrointestinal tract, gills and bloodstream and provide degranulation when there are parasites infestations. Basophils are unusual in most fish. The special granulocytic cell are polymorphonuclear cells found in the blood mainly in parasitized fish or injected with inflammatory agents but their exact function is still unknown. The phagocytes described below play an important role in innate immune system modulation since they have phagocytosis ability with consequent pathogen destruction.

T and B lymphocytes are the adaptive immune system cells, however, there are distinct populations of lymphocyte called natural killers or T cytotoxic that have been classified as an innate immune compound and relies on the ability to destroy injured somatic cells (tumor or viruses infected cells) and produce immune modulation cytokines.

Some cells are able to trigger phagocytosis of invading particles, such as microorganisms, cells, cell debris and macromolecules aggregates, in order to destroy or present them to the specific system cells. Phagocytosis is initiated by the connection between the agent and the phagocyte receptor membrane. Monocytes, macrophages, dendritic cells and granulocytes are professional phagocytes that may be mobilized to the inflammation site by molecular signals of inflammation (cytokines) released by injured tissue.

Neutrophils and macrophages destroy microorganisms through phagocytosis with hydrolytic enzymes and reactive oxygen species (ROS). The inflammatory tissue liberates chemotaxis factors that promote cell migration. Neutrophils are the first granulocytes to appear at the injured site, followed by macrophages. Neutrophils migrate from the bloodstream and macrophages are originated from blood monocytes. At the site of injury, these cells trigger the phagocytosis process, in order to destruct invading agents.

During the phagocytosis there is increased oxygen consumption in a molecular mechanism known as leukocyte respiratory burst which result in oxygen reduction with superoxide anion production. The superoxide dismutase enzyme acts over the superoxide anion and generates hydrogen peroxide, in addition myeloperoxidase enzyme released by granular leukocytes react with hydrogen peroxide in order to produce hypochlorite that lead to the production of cloramins. All of these compounds are oxidative substances and can attack microorganism membranes.

The relationship between innate and acquired immune system is made by antigen-presenting cells (dendritic cells and macrophages) that after processing microorganism introduce the processed molecule to T lymphocytes with the help of major histocompatibility complex (MHC), class 2 receptors, thus initiating the acquired response cell mediated. Histocompatibility molecules are glycoprotein receptors encoded by a gene complex, which are expressed in almost all organism cells. MHC plays an important role for endogenous and exogenous antigens recognition but lacks in specificity and may recognize several related antigens.

On the other hand, antibodies are glycoproteins, known as well as immunoglobulins (Ig), expressed in the membrane of the B lymphocyte (BCR) or free in body fluids, secreted by plasma cells (B lymphocytes activated by antigen connection). The immunoglobulin IgM is a tetrameric protein with four sites for antigen recognition well known in fish. However, researchers have observed other immunoglobulins in some species of fish, such as the IgD, IgZ and the IgT. Immunoglobulins can be found in the serum, body fluids, mucus, eggs and in the gastrointestinal mucosa.

The antibodies may develop several roles such as anti-adhesin function which mainly occurs in the epithelium of digestive system surface, gills and skin, so that these antibodies prevent bacteria adherence. Antitoxins antibodies neutralize toxins produced by countless bacteria. Anti-invasins antibodies avoid bacteria infiltration into unprotected cells.

Regarding specific immune response, once antigen have been recognized by immunoglobulins receptor of B lymphocyte, it will stimulate endocytosis and proliferation of memory B cells, which activate T lymphocytes, resulting in cytokines release and triggering of B cells, macrophages, among others cells. The serum antibodies concentration may differ according to species, age, sexual maturity and physiological events (natural or artificial incident – as smoltification, cortisol boost, etc) and may be increased by artificial immunization or due to chronic infection.

Among the humoral innate components are the inhibitory factors of bacteria growth, such as transferrin, antiproteases, lysozyme, C-reactive protein, antibacterial peptides and complement system proteins, activated through alternative and lectin pathways. The complement system is one of the most important mechanisms since it has lytic activity, chemotaxic, pro-inflammatory and opsonization functions. Defense cells represented by phagocytes, neutrophils and macrophages are very important due to their large quantities of enzymes in lysosomes and reactive oxygen species produced during phagocytosis.

(a)Antiproteases: Antiproteases are blood proteins which act against microorganism proteolytic proteins, those ones that make lysis in fish tissues in order to obtain amino acids as sources of energy. Lectins are proteins found in eggs, mucus and blood that promote agglutination due to their high affinity for carbohydrates of the pathogens cell wall. Lysins present in mucus are peptides that attack the membranes of pathogens.

(b) Lysozyme: Lysozyme is produced by leukocytes (mainly monocytes and neutrophils) and it is found in mucus, eggs, blood and tissues and acts on the peptidoglycan of pathogens cell wall

(c) C-reactive Protein: C-reactive protein from the pentraxin family is found in large concentrations in the blood, egg and mucus. The protein recognize and connect to phosphoryl colin, a component usually found on the walls of various microorganisms such as bacteria, fungi and parasites. The C-reactive protein and the mannose binding lectin are considered inflammation acute phase proteins and receptors of soluble microbial components so that they have ability to connecting and promoting pathogen opsonization, complement activation and phagocytosis. The concentration of acute phase proteins may increase after heat shock (high temperatures), infectious agents and in warm periods of the year.

(d) The Complement System Proteins: The complement system of fish is considered more effective than that of mammals and is one of the most important innate compounds for host protection due to its production of inflammatory mediators. The complement system is comprised of soluble and membrane proteins in inactive form or in low levels of spontaneous activation and they are triggered by sequential pathway since the initial stimulus contributes to the proteolysis of the next component.

Activation can be triggered by three pathways:

i) Classical pathway, an antibody-dependent activation by antigen-antibody complex,

ii) Alternative pathway, prompted by microorganisms Pamps or antigen-antibody complex,

iii) Lectin pathway, triggered by bacterial surface carbohydrates.

The alternative pathway is very efficient on innate recognition and is considered the most important among the three activation pathways, besides it can be easily trigged by various gram-negative bacteria lipopolysaccharide and cause cytolysis. Alternatively, the classic pathway performs interaction between innate and specific systems.

Two complement system components C5a and C3b play a central role in the recruitment of phagocytes and inflammation. C5a and C3b are chemotaxic proteins for neutrophils and macrophages because they remain linked to bacterial wall triggering biological processes of opsonization, phagocytosis, and chemotaxis of leukocytes and inactivation of the released bacteria toxin. The complement system is widely used as an immune status indicator due to its contribution to host protection. The function of the complement system regarding cellular activation, phagocytosis, chemotaxis, inflammatory reaction and lise of pathogens cells are well known mainly for their ability to destroy pathogens through membrane injuries, commonly characterized by pores.

Innate humoral components increase after outbreak of pathogens such as bacteria, viruses, parasites and fungi, as well as in trauma, necroses, chemicals, heat shock, tumor cells and in some cases increase up to

1000 folds, such as C-reactive protein. These compounds are called acute phase proteins and most of them are synthesized by the liver, however, they can also be synthesized by the brain and leukocytes. The C-reactive protein, serum amyloid A, transferrin, α-2 macroglobulin, C3 complement, lysozyme and lectins are commonly used for the diagnosis of diseases.

11.7 FISH ANTIBODY AND THEIR EFFECTOR FUNCTION

Immunoglobulins or antibodies, which play a vital role in adaptive immune responses, are heterodimeric glycoproteins belonging to the broad Ig superfamily (IgSF). Antibodies were first reported by von Behring and Kitasato in 1890 as an agent in the serum that could neutralize diphtheria toxin.

The basic structure of Ig consists of two identical heavy (H) chains and two identical light (L) chains. Both heavy and light chains contain one N-terminal variable domains (VH or VL) and one or more C-terminal constant domains that form the constant region (CH or CL), all domains adopting the hallmark fold of the IgSF. Variable domains participate in antigen recognition and the domains that comprise the constant regions mediate effector functions of the antibody molecule. Such humoral immunity mediated by Ig includes opsonization of pathogens for destruction by phagocytes, neutralization of toxins and viruses, and activation of the complement cascade. The variable region paratope (that engages the epitope of the antigen) is formed by variable domains of IgH and IgL (one variable domain in each chain). Constant regions consist of constant domains of both IgH and IgL as well. While IgL have one CL domain, the number of constant domains of IgH varies among different immunoglobulin classes.

There are three hyper variable regions within each VL and VH domains termed complementarity-determining regions (CDR). The three CDR segments of VL domain and the three CDR of VH domain together contribute the majority of the antigen binding site of the Ig molecule. Different combinations of CDR in VL and CDR in VH diversify the antigen binding site amongst the millions of different antibodies in an individual. Antibody repertoires are tremendously diverse which enables them to recognize a vast array of distinct antigens.

Inter-chain disulfide bonds between cysteines hold together IgH and IgL and also the two IgH. The number and location of these bonds differs amongst Ig class and amongst species. There are also intra-domain disulfide bonds within each domain of each chain. The assembled chains of antibody assume a "Y" shaped quaternary structure in which amino terminal fragment antigen-binding (Fab) and fragment crystallizable (Fc) stabilize using a flexible polypeptide hinge region between the first and second CH domains. The flexibility of the hinge region will allow the Fab fragments to pivot freely and independently from one another, allowing the binding of two identical epitopes. This flexible bivalency of the Ig facilitates crosslinking of multivalent surface epitopes of pathogens.

In cartilaginous fish, three heavy chain isotypes have been detected: IgM, IgD/W, and IgNAR. Thus far, in teleost fish, three different Ig heavy chain isotypes have also been identified: IgM, IgD, and IgT/Z.

CARTILAGINOUS FISH

1. IgH: Cartilaginous fish are phylogenetically the most ancient vertebrates capable of undergoing an IgSF-based antibody response. The cartilaginous fishes (Chondrichthyes) diverged from a common ancestor with the lineage leading to other bony vertebrates ~450 million years ago (MYA). They are the most distantly related group to mammals having an immune system grounded upon Ig, TCR, the MHC, as well as recombination activating gene (RAG)-mediated rearrangement, somatic hypermutation (SHM), and the presence of primary and secondary lymphoid tissues. Cartilaginous fishes are divided into two subclasses, the Holocephali (ratfishes, chimaeras, elephant sharks and rabbitfishes) and the Elasmobranchii (sharks, skates and rays). Cartilaginous fish do not have bone marrow but instead it uses the epigonal organ associated with the gonads and the Leydig organ embedded within the walls of the esophagus as the tissue responsible for B cell lymphopoiesis. In the absense of lymph nodes, the white pulp of spleen is the major secondary (or peripheral) lymphoid tissue in the cartilaginous fish, but the gut associated lymphoid tissues have also been implicated.

2. IgM: A potential candidate for IgM was discovered 50 years ago in the spiny dogfish shark (Squalus acanthias) serum. IgM is considered the most ancient antibody molecule which shares similar functions in all gnathostomes. IgM was thought to be used in all jawed vertebrates, until work in the coelacanth found it to be extinct representative of the Sarcopterygian lineage as the only known jawed vertebrates to lack IgM. Both during ontological development and in the course of adaptive humoral immunity, IgM was the first isotype expressed, and it is the major B cell receptor on the surface of both conventional B2 and “innate” B1 and marginal zone B cells. IgM is known for conserved form and function across all vertebrate classes. However, it does display different polymerization states in secreted antibody and a significant splice form in bony fish. In cartilaginous fish, IgM is a major serum protein that accounts for more than 50% of serum protein. IgM is usually expressed in eye, gills, intestine, liver, pancreas, peripheral blood leukocytes, spleen and testis but not in brain, heart, kidney, muscle, skin and stomach. IgM has been considered to have important roles in more ancestral clades of vertebrates in addition to antigen binding. One hypothesis is that IgM has a role in blood osmoregulation analogous to the physiology of albumin in other vertebrates. Shark IgM antibodies have been shown to be active in lytic, opsonic and antibody induced cytotoxicity-like reactions. This killing is observed through phagocytosis which is mediated by both 7S and 19S IgM antibodies. Throughout evolution, IgM reacts with particulate antigen and through binding FCμ receptors on the surface of leukocytes enhancing phagocytosis. Neutrophils appear most frequently associated with IgM mediated phagocytosis.

3. IgW: IgW, which was first discovered in skates, later in shark, and then coelacanth, has gone by many names (IgX, IgNARC or IgR) before being proposed as an ortholog of IgD. Nearly 500 MYA in the first jawed vertebrates IgM and IgW evolved in a relatively short period of time. IgD is orthologous to IgW, found only in cartilaginous fish and lungfish, demonstrating that IgD/W, like IgM, was likely present in the ancestor of all living jawed vertebrates. IgW has been detected to be highly expressed in the shark pancreas, much less in muscle, and faintly in gills, kidney, spleen and testis. Cartilaginous fish IgW exists as either a seven-domain or three-domain form, but in lungfish it can have two to at least 11 C domains. Similar to IgM, IgW is encoded at loci employing the multiple cluster organization. In nurse shark, eight loci encoding the IgW CH have been characterized. Each cluster contains six to eight C domain exons in addition to V, D and J segments. The IgW H chain long form is composed of seven domains in all cartilaginous fish so far studied and eight domains in the lungfish which is homologous to IgW-long. An IgW short form consisted of three domains which appears to be spliced differently than the long form. Two cell bound forms (containing two and four Cδ) and at least seven secreted forms (containing two, four, six or eight Cδ as well as a six Cδ form that lacks a V region) have been found thus far, all of which can be generated by alternative RNA splicing.

4. IgNAR: IgNAR (new or nurse shark antigen receptor) was first reported in 1995 by the Flajnik group in nurse shark and contains one V and five C domains. The carboxy-terminal C domains have homology to those of IgW long. Most notably, it is found as a dimer in serum without light chain. IgNAR has been found in intestine, liver, pancreas, peripheral blood leukocytes, spleen and testis. Similarly as in IgM and IgW, IgNAR genes are organized in the multiple cluster format. Each genomic IgNAR cluster comprises one V segment, up to three D segments and one J segment and one set of C segments. Rearrangement occurs solely within this cluster resulting in a V (D1D2D3) JC assembly. Hence, up to four RAG-mediated rearrangements can proceed to generate the mature exon encoding the complete V NAR domain. Consequently, diversity in both sequence and length of the primary repertoire is focused in CDR3. Extensive junctional diversification through N-region addition, P-nucleotide addition, exonuclease trimming, and D-region rearrangement further expands the heterogeneity of the primary repertoire of IgNAR. The multiple rearrangement events vary CDR3 length greatly (range 5–34 aa). IgNAR V elements then undergo much somatic hypermutation in response to antigen.

5. IgL: In cartilaginous fishes, some IgL loci are capable of rearrangement while others contain germline fused V-J genes. In all species studied, λ (type II) L chain genes are all germline-joined, but there are widely varying numbers of IgL genes in different species for different isotypes. The σ-2 (type I) genes are all joined in skates and split in the horn shark. Nurse shark λ genes are completely joined, but there are only six loci. IgLκ (type III) genes are expressed at the highest levels, and it is estimated that there are approximately 60 genes present in the genome. Most of the nurse shark κ genes are split, but a few are germline-joined. There are only three expressed σ-2 (type I) genes, two being split, each consisting of a V and J gene segment that can recombine and one C region, and one germline-joined V-J in-frame and the fourth locus is a pseudogene in this species.

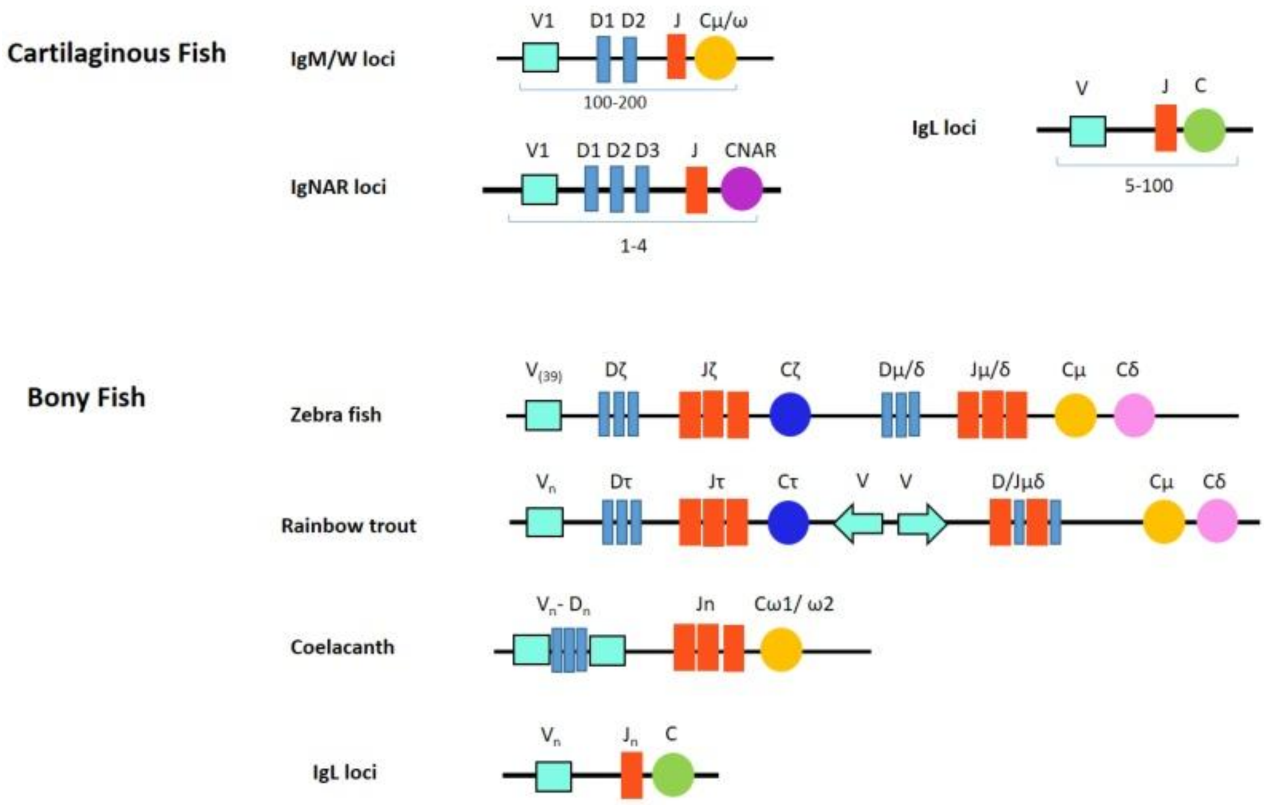

Fig.11.3: Fish Antibody System and Their Effector System

BONY FISH

1. IgH: Almost every aquatic niche on the planet has been colonized by Osteichthyes, or bony fish. Over 40,000 species exist and account for more than 50% of all known vertebrate species. The infraclass of Teleostei represents approximately 96% of the species of this superclass. Osteichthyes are further split into the Sarcopterygii or "lobe-finned" fishes (which include the coelacanths and lungfishes which are closest in relation to tetrapods), and the Actinopterygii or "ray-finned" fish, the latter where most fish are placed.

Like chondrichthyes, Osteichthyes have thymus and spleen. Osteichthyes employ the head kidney or pronephros for hematopoesis and B lymphopoiesis.

Fish B cells express TM BCR on their plasma membrane and in response to antigen will secrete antigen-specific Sec antibodies. Three classes of Ig have been identified in teleost fish. These are IgM, IgD, and IgT/Z (for Teleost/Zebrafish), which is specific to fish. IgM and IgD are ubiquitously found in most fish species as well as most vertebrate classes, leading to hypotheses that they are ancestral isotypes. The fundamental immune molecules, including Ig, TCR, MHC, AID and RAG, appear similar in cartilaginous fish, bony fish and mammals.

Ig of teleost fish is found in the skin, gut, gill mucus, bile, and systemically in the plasma. Most fish respond to primary antigenic challenges by producing specific antibodies, whereas the response to secondary challenge is generally faster and of greater magnitude. This makes vaccination an attractive strategy for control of infectious disease in the aquaculture industry.

2. IgM: Teleost serum contains natural IgM antibody before immunization, but antigen exposure with T cell helps drive release of specific tetrameric IgM. Serum IgM concentrations have been found between 800 and 9000 µg/mL in teleosts. Bony fish IgM is secreted in redox forms that may affect binding affinity. Antibodies are also found in the channel catfish epithelial mucus, and specific antibody was detectable in higher titers in the intestinal extract from orally immunized fish, than in the sera and vice versa, parenteral immunization resulted in high and persistent antibody titers in the serum, but not in the intestinal and cutaneous secretions. IgM contributes to both innate and adaptive immunity in fish. IgM effector functions include complement activation which both lyses and opsonizes pathogens. IgM also mediates agglutination for phagocytosis and removing pathogen, and cellular cytotoxicity.

3. IgD: IgD was first discovered in human serum in 1965. One proposed role for Sec IgD is high affinity binding to an as yet to be identified receptor of basophils and induce the production of antimicrobial, opsonizing, pro-inflammatory, B cell activating factors. When initially described, IgD was thought to be a recently evolved isotype of some mammals. However, in the last decade, IgD has been found in many vertebrate classes suggesting that it may be as old as IgM. Channel catfish was the first teleost in which IgD was identified. The concentration of IgD in serum is 2–80 µg/mL. IgD secreting cells can be found in anterior and posterior kidneys, spleen and gills.

4. IgT/IgZ: Bony fish are the only animals that produce IgT/Z. IgT/Z was first identified in rainbow trout (IgT) and zebrafish (IgZ). Subsequently, the isotype was discovered in most model species of teleost, with the notable exceptions of medaka and channel catfish. The IgT/Z organization within the fish IgH locus encodes a varying number of C domains in different species.

5. IgL: Among teleost species, the humoral immune system of salmon, medaka, trout, zebrafish, catfish and cod have been best characterized. To date, four IgL isotypes, orthologous to λ, κ (previously called L1, L3, F or G, and now called Ig κF and Ig κG) σ (otherwise known as L2) and σ-2, have been identified in bony fish.

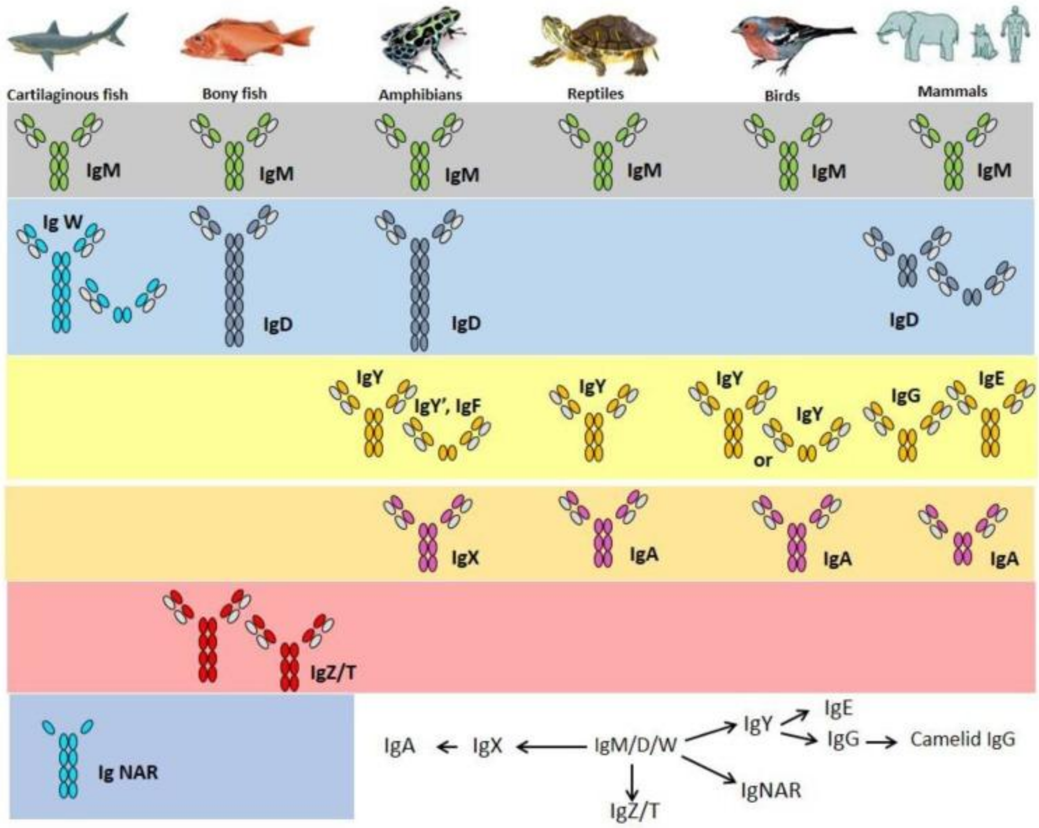

Fig.11.4: Comparision of Immunoglobulins in Vertebrates

11.8 HOST –PARASITE INTERACTION

When a parasite gains access to a host, the host has to compromise, and the parasite has to adopt itself in host environment. In this way host and parasite establish a sort of relationship which effects each others growth, metabolism, etc. In general the series of events that constitutes the relation of host and parasite may be considered as beginning with the transmission of parasite from one host to another, then follows the distribution and localization of parasite on or within the host, then growth or multiplication of parasite, the resistance of host to the parasite and the parasite to the host. The method of attack of parasite, changes in host brought about by parasite and those in parasite due to residence in host. Host parasite adjustments during the infection, the escape of infective stages of the parasite from the host and then the recovery or death of host.

HOST-PARASITE RELATIONSHIP STRATEGY

In the host-parasite relationship, we can identify two categories of bio-physiological function. These are:

1. Parasite invasiveness which is aimed to obtain entry into the host and continue its life within the host, and

2. Host resistance which tends to prevent the invasion of parasite and its colonization. In a host-parasite relation we can see that both these functions counter each other thereby acting as a check to maintain balance in the host parasite relationship.

When a parasite is growing and multiplying within or in a host, the host is said to have an infection

Host-parasite interactions are complex, compounded by factors that are capable of shifting the balance in either direction. The host's age, behaviour, immunological status, and environmental change can affect the association that is beneficial to the host whereas evasion of the host's immune response favours the parasite. In fish, some infections that induce mortality are age and temperature dependent. Environmental change, especially habitat degradation by anthropogenic pollutants and oceanographic alterations induced by climatic, can influence parasitic-host interaction. Moreover, this interrelationship between hosts and parasites has evolved some associations resulting in host specificity, latitudinal gradients, and diversity in communities and siblings within one species.

It was noted that a hemoflagellate, *Trypanosoma murmanensis*, was more abundant in blood from the gills of Atlantic cod, Gadus morhua, at night when the vector, a marine leech, *Johanssonia arctica*, fed on its piscine hosts than during daylight. The leech, a deep-water (>90 meters) species inhabiting the benthic zone where light is probably negligible, was significantly more abundant than at shallow depths (30 meters) where some light penetrates. Some parasites can also avoid their host's defence mechanisms. Cysticerci of *Taenia solium* which infect the human brain, a site impervious to the immune response, are protected from destruction by the host. Similarly, plerocercoids of the fish tapeworm, *Proteocephalus ambloplitis*, avoid shedding from the intestine of its host by migrating into parenteral sites as the water temperature declines in winter, a period when feeding is reduced and worms voided because of a lack of nutrients. However, the parasites reenter the intestine as the water temperature increases in spring to mature as adult tapeworms. Some tissue-invading parasites can become encapsulated by fibrous tissue in their hosts as a result of the latter's defence mechanism and appear as cysts. They might remain viable for lengthy periods until acquired by new and/or appropriate definitive hosts.

The immune response to foreign proteins in fish is lower in magnitude compared to mammals. Some of the defense barriers include mucous in the skin and gills, bile, digestive enzymes, and immunological barriers, primarily cellular and antibody responses. Some of these hinges on age of the host and ambient water temperature. A parasite's specificity will also determine if an infection becomes established. For example, a hemoflagellate, *Cryptobia salmositica*, is infective to some salmonid species but *Salvelinus namaycush* exhibits innate resistance. Lytic antibodies were responsible for resistance but these apparently were absent in *S. fontinalis* that was susceptible to the infection. Cellular response is observed when some tissue-invading parasites become encapsulated. The immune response is temperature dependent as larval anisakine nematodes ingested in late autumn-winter, when water temperatures range from 0 to 4 EC, remain free in the tissues of Atlantic cod, *Gadus morhua*, whereas in summer, most become encapsulated.

Some environmental factors have a profound effect on several fish-parasite interactions. Generally, ectoparasites differ from endoparasites as the defence mechanisms tend to be reduced externally in fish. The interaction between an ectoparasitic ciliate, *Trichodina murmanica*, and its host, the Atlantic cod, is age and temperature-dependent. Prevalence and abundance of the parasite on the skin of 1-year juvenile fish in nature are extremely low and rare in older fish. However, outbreaks have occurred in fingerling and 1-year fish cultured cod held in over-stocked conditions during winter when water temperature was 0-1°C. The infection and mortality declined with increasing water temperature and were rarely seen during summer at 8–14°C. Infection of Atlantic cod with *Trypanosoma murmanensis* was also age and temperature dependant as mortality was greater in younger than older fish. Moreover, the infection persisted for longer periods (6–8 weeks) at lower (0–2°C) than higher (10–12°C) temperature. It is probable that the host's immunity is temperature-dependent or the parasite is adapted to low temperatures as noted in some subarctic marine leeches.

The host-parasite interactions are complex, at times difficult to interpret on account of a number of variables that can shift the balance one way or the other. Factors such as host's age, behaviour, immunological competence, and environmental change can play a role in the association. Alternatively, establishment and evasion by the parasite of the host's responses appear to be significant factors. Consequently, the outcome in this interaction will hinge on host susceptibility and resistance and the parasite's ability to infect its host.

11.9 SUMMARY

The immune system is a set of cellular and humoral components to defend the body against foreign substances, such as microorganisms, toxins or malignant cells, responding to factors such as endogenous or exogenous components that stimulate this system. The fish immune system is divided into innate and adaptive (memory), both divided into cell mediated defense and humoral factors (soluble substances), although today it is known that these two systems work together in order to destroy invaders or to trigger defense processes. The innate system includes all components present in the body before the appearance of the pathologic agent, as the first line of defense that acts faster than the specific system. Among these components there is the skin as a physical barrier, the complement system, the antimicrobial enzymes, the interleukins, the interferon and the organic defense cells, such as granulocytes, monocytes, macrophages and natural killers cells. The inflammation is also considered an innate mechanism of immune response, mediated by complex interactions of cellular and humoral compounds. Once a tissue has been penetrated by an infectious agent, mediator factors are released in order to extend and make blood capillaries more permeable, allowing the migration of the defense cells. The granulocytes are the first cell type to arrive at the inflammation focus, being responsible for the destruction of pathogens. On the other hand, the remaining pathogenic cells and cellular debris are phagocytosed by macrophages. The innate immunity is the oldest system in the phylogenetic scale and probably originated in unicellular organisms during the evolutionary period. By definition, this system recognizes regions in molecules called Pamps - Pathogen Associated Molecular Patterns - from infectious agents or microorganisms of normal microbiota, such as lipopolysaccharide, peptidoglycan, bacterial DNA or viral RNA, or other molecules found in multicellular organisms membranes known as "non-self". The Pamps are usually highly preserved portions during the evolution of species and are found in the greater part of microorganisms. Conversely, the specific system first appeared around 450 million years ago, and can be found in all vertebrates except in fish of the Agnatha class. The acquired system receptors are responsible for detecting the pathogenic agent, and can be found in the cell membrane of T lymphocytes (TCR - T cell receptor) and B lymphocytes (BCR - B cell receptor, also called as well as membrane immunoglobulin) or in serum as free antibody. The specific system of defense requires the presence of an antigen, which is a strange molecule or cell that will initiate reactions and culminate in the increase of circulation of specific antibodies, besides promoting immune memory. Antigens that enter the body will be recognized and processed by the innate system by antigen presenting cells (APC - macrophages, dendritic cells and B lymphocytes), to process microorganisms in molecular units, and at first trigger immune response of proliferation, and in a second moment, the response of memory. As a result, the antigen processed by APC will be presented to the T lymphocytes which are the cells of the specific system. T lymphocytes carry the ability to recognize the antigen strictly in the presence of a specific humoral component called major histocompatibility complex molecules, which are glycoprotein receptors coded by genes in a major histocompatibility complex (MHC).

After this recognition, the T cell secretes cytokines, which are proteins that activate other cells such as B lymphocytes (responsible for the production of antibodies), cytotoxic lymphocytes, macrophages and other cells in order to destroy the invading agent. The antibodies recognize and connect to specific microorganisms and consequently activate phagocytosis (component of the innate system, indicating that the specific and innate systems act together). Antibodies may promote agent neutralization or opsonization and may bind to extracellular antigens in addition to complement system. However, if the antigen is established in the intracellular compartment, the defense is conducted by cytotoxic T lymphocytes.

11.10 TERMINAL QUESTIONS AND ANSWERS

Q1. What is the immune system of fish?

Q2. Explain active immunity in fish.

Q3. Expalin Humoral immunity.

Q4. Explaind Cell-mediated immunity.

Q5. Write a note on development of immune system in fish.

Q6. Write an explanatory note on primary and secondary lymphoid organ in fish.

Q7. Write down the functions of antibodies in fishes.

Q8. Expalin the difference between primary and secondary immune responses.

Q9. Write in detail about the host –parasite interactions.

Q10. Describe briefly about the modulation of immunity in fishes.

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UNIT 12: REPRODUCTIVE SYSTEM

CONTENTS

12.1 OBJECTIVES

After studying this module, you shall be able to learn and understand:

(i) Oragans of reproduction

(ii) Gametogenesis

(iii) Gonadal hormone synthesis and their role

(iv) Effect of environmental factors

(v) Parental Care

(vi) Reproductive behaviour

12.2 INTRODUCTION

Reproduction means to reproduce i.e. producing biologically or genetically similar copies of individual. Fishes show various methods of reproduction, but mostly fishes lay a large number of small eggs. The eggs of pelagic fishes usually remain suspended in the open water. Many shore and freshwater fishes lay eggs on the bottom or among plants. Some fishes have adhesive eggs.

Males produce sperm, usually as a milky white substance called milt, in two (sometimes one) testes within the body cavity. In bony fishes a sperm duct leads from each testis to a urogenital opening behind the vent or anus. In sharks and rays and in cyclostomes the duct leads to a cloaca. Sometimes the pelvic fins are modified to claspers (Fig. 12.1) to transmit the milt to the eggs at the female's vent or on the substrate where the female has placed them, for example, the claspers of many sharks and rays. Sometimes accessory organs are used to fertilize females internally-for example gonopodium (Fig. 12.2). In female in two ovaries (sometimes only one) are found. The ovaries produce eggs and these pass from the ovaries to the urogenital opening and to the outside.

Fig.12.1: Male copulatory organ of shark: Claspers found in pelvic fins (Courtesy: Jean-Lou Justine, Wikipedia)

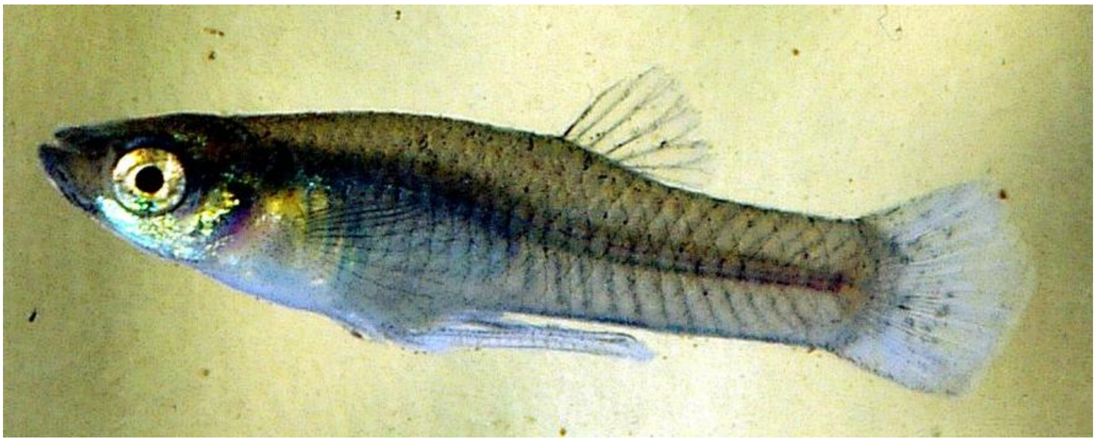


Fig. 12.2: Male Gambusia affinis has a gonopodium in an anal fin which functions as an intromittent organ (copulatory organ) (Courtesy Nozo, Wikipedia)

12.3 TYPES AND MODES OF REPRODUCTION

There are two types of reproduction:

1. **Sexual reproduction**
2. **Asexual reproduction**

SEXUAL REPRODUCTION

The process of the production of new organisms by the combination of genetic information of two individuals of different sexes is known as sexual reproduction. In the sexual reproduction there is the fusion of gametes (two reproductive cells) i.e ova and sperm by the process of fertilization. The ova or eggs and the sperms are produced by females and males respectively. In fishes the female produces the large number of eggs. The female produce eggs or ova which is fertilized by sperm from the male. After the female lays her eggs and the male releases his sperm close by. Fertilization is the species specific process. Depending on the species, fertilization takes place either internally (within the female's body) or externally. When the egg is fertilized by the sperm, the genes of both parents are combined to produce zygote which develops into a new individual. Nearly all animals reproduce sexually. We can classify the fishes according to the presence of gonads:

BISEXUAL

As a rule fishes are bisexual animals which means ovary and testis are found in two different individuals. This difference in sex persists throughout life.

HERMAPHRODITES

When both sexes are found in one individual is known as hermaphrodites. There are over 100 species of fishes throughout the world which are hermaphrodites. There are even some cases where the individual specimen changes sex after spawning (sex reversa1). For instance, *Lates calcarifer* are protandrous hermaphrodites, here males often change their sex after spawning. Hermaphroditism probably evolves when there is difficulty to find the mate due to some environmental conditions or where there is a differential size between the two. In many tropical fishes sexes become exceedingly variable. Sometimes in the mature (gravid) population all the individuals are males (*Jenynsia*) (Fig.12.4) at other times almost entirely females (*Molliensia*) (Fig.12.5). If male is smaller than its female partner, larger proportion of male offspring may be expected, on a contanary if the female partner is equal to or smaller than the male, the offspring will be mostly females. Hermaphroditism generally seen in the species belonging to Serranidae, Labridae, Scaridae and Sparidae. It is noticed when individuals belonging to these families grow under induced circumstances, they change there sex i.e. females change to males (protogynous) (Fig. 12.6). The family Pomacentridae show reverse change i.e. (protandry) males change to females (Fig. 12.7). There are number of factors which induce sex reversal in fishes. They are: It has also been suggested that (i) Sex change can be triggered by sex-ratio threshold (i.e. If there is a great disproportion in the number of males and females).

(ii) The physiological changes in fish induces sex reversal (sex reversal may be different in different groups of fishes).

(iii) The environmental factors also induce sex reversal in fishes.

In true hermamaphrodite fishes eggs and sperms develop in the same gonad and self fertilisation takes place in those fishes usually testes ripen first and the ovaries later. However, in some cases the ovaries ripen first than the testis.

Fig. 12.3: Lates calcarifer (Courtesy: Indian Buodiversity Portal)

Fig. 12.4: Jenynsia (Courtesy: Chucao: Wikimedia Commons)

Fig.12.5: Mollienisia sphenops (Courtesy: Shutterstock)

Fig.12.6: Many female groupers (Family: Serranidae) change their sex to male if no male is available (Courtesy: NZ Animals)

Fig.12.7: Clown Anemone Fish (Amphiprion ocellaris) If the female dies, a juvenile male moves in, and the resident male changes sex

ASEXUAL REPRODUCTION

The process of reproduction in which new individuals are produced without the formation of gametes and fertilization. In asexual reproduction animals reproduce without a partner. It occurs chiefly in lower animals, microorganisms, and plants. Many invertebrates reproduce asexually, including coral and starfish by the process of budding. In fishes parthenogenesis is a kind of asexual reproduction in which new individuals are produced from an unfertilized egg. First it was reported in Amazon molly fish (*Poecilia formosa)* in the year 1932. All members are females (unisexual). There are approximately 20 species of fish which reproduce by the process of parthenogenesis. In sharks parthenogenesis has been reported in the bonnethead and zebra shark. Some sexual species of sharks, may occasionally reproduce parthenogenetically like hammerhead and blacktip sharks Gynogenesis is a special form of parthenogenesis, in which asexual reproduction requires the presence of sperm without the actual contribution of its DNA for completion. In gynogenesis, the egg is stimulated to develop by the presence of sperm and the sperm cells do not contribute any genetic material to the offspring. The paternal DNA dissolves or is destroyed before it can fuse with the egg. Because gynogenetic species are all female, activation of their eggs requires mating with males of a closely related species for the needed stimulus. The Amazon molly reproduces by gynogenesis. In nature, with a male from one of There are four different species of males found in nature by which the Amazon molly typically mates *P. latipinna*, *P. mexicana*, *P. latipunctata*, or occasionally *P. sphenops*. One other male that could possibly exist in the Amazon molly's natural range that could induce parthenogenesis in Amazon molly females is the triploid Amazon molly males. These triploid males are very rare in nature and are not necessary in the reproduction of the species, which is why the species is considered to be all female.

Fig. 12.8: Amazon molly fish (Poecilia formosa) (Courtesy: Researchgate)

12.4 ORGANS OF REPRODUCTION

TESTES

Fish reproductive organ includes testis and ovaries. In most fishes testis are paired, lobulaled structures and remain separated. They lie close to the kidneys and attached by mesentry called mesochorium to the dorsal body wall. Mesochorium is richly supported by blood vessels and nerve fibres. In elasmobranchs, the testes extend from the base of the liver to the rectal glands near the cloaca. The proximal part of the testis is attached with the rectal gland of each side through a 'band of non- glandular tissue. In teleosts testis are generally separated as they do not have rectal gland. The size and colour of the testis varies even in the same individual at different maturity stages. Normally in mature individuals testes are flat, white in colour and their ventral edge frequently have wave like outline (Fig. 12.9) while in immature males, it is generally whitish or greyish in colour.

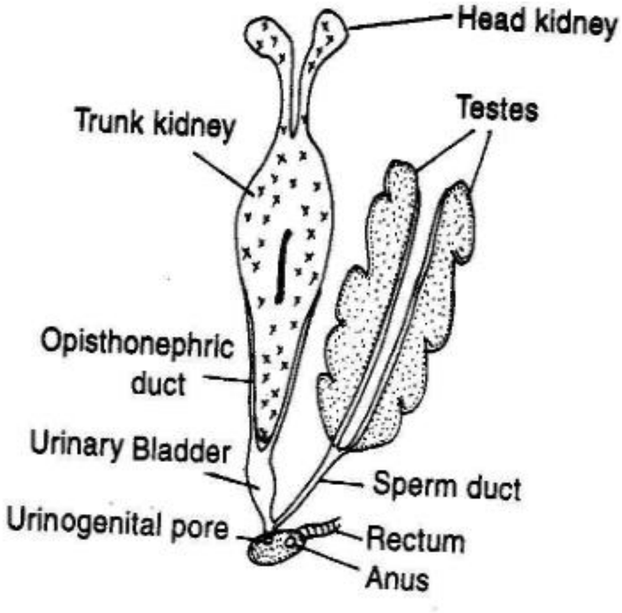


Fig.12.9: Testes of teleost fish

Histologically, the testes composed of many closely compact and highly convoluted tubules, known as seminiferous tubules. The seminiferous tublules are the structural and functional unit of testis. The tubules are connected to each other by a thin layer of connective tissue. Other than connective tissue, the spaces between the lobules are also filled with blood capillaries and specific type of cell known as interstitial cells or Leydig cell. From the Leydig cells the male hormone is secreted. In teleosts, the seminiferous tubules open directly in to a spermatic duct which is usually lined by a secretory epithelium. In elasmobranchs, from each seminiferous tubule a capillary tube is arising from which spermatozoa are carried is known as vasa efferentia. The vasa efferentia open to a longitudinal duct called vas deferens (Wolffian duct) and the two Wolffian ducts from two sides ultimately terminate into the cloacal chamber. During spermatogenesis, sperm mother cells undergo cell division and give rise to primary spermatocytes. From primary spermatocytes smaller secondary spermatocytes arise through mitotic divisions. The latter divides to produce spermatids which are further reduced in size and contains an elliptical nucleus in its substance. The spermatids again undergo cell division and give rise to tiny sperms. It is interesting to note that the entire testis may be functional in all fishes. In certain species (eg.

Tor tor) only the anterior portion contains germ cells and the posterior sterile probably serves for the storage of sperms during the spawning season.

HISTOLOGY OF THE TESTIS: The structure of the testis is variable in teleosts, and two types have been recognised: (i). Lobular type and (ii). Tubular type. Most teleosts have typical lobular type of testis consisting of a large number of seminiferous lobules which are closely bound together by a thin layer of connective tissue. The lobules are of various sizes and are highly convoluted structures, separated from each other by a thin connective tissue stroma. The walls of the lobules are not lined by a permanent germinal epithelium. The lobules open into a spermatic duct which is generally lined by a secretory epithelium. In some species as *Glyptothorax, Rita rita*, the lobules, project out individually from the sperm duct and are not bound together into a compact mass, as found in most teleosts: The lobules of the testis may be surrounded by lobule boundary cells which resemble connective tissue cells. The spaces between the lobules are filled with connective tissue, blood capillaries and interstitial cells. Within the lobules, the primary spermatogonia undergo mitotic divisions to produce cysts containing spermatogonial cells. As maturation proceeds, cysts enlarge and finally rupture to liberate sperm into lumen of the lobule which continues into the sperm duct. The second tubular type of testis is found only in Atheriniformes (e.g., *Poecilia reticulata*). In this type the tubules are arranged regularity between the external tunica propria and the central cavity. There is no structure comparable to lobular lumen in this type. The spermatogonia (germ cells) are restricted to the distal end of the tubule, immediately below the tunica albuginea. The spermatogonia are endodermal in origin. Spermatogonia divide in clusters enclosed by a cyst. Primary spermatogonia, which are present throughout the year, divide mitotically to give rise to secondary spermatogonia which get transformed into primary spermatocytes. They divide by meiosis and give rise to spermatids from which spermatozoa are formed. The seminiferous tubules are packed with spermatozoa in the pre-spawning and spawning periods

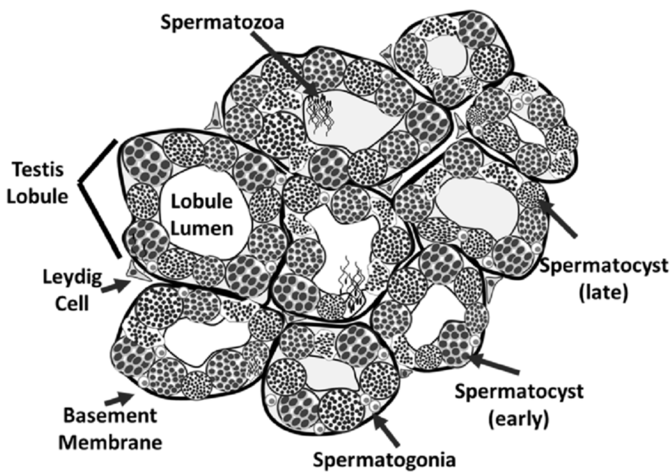


Fig. 12.10: T.S. of testis of coral reef fish (Courtesy: Researchgate)

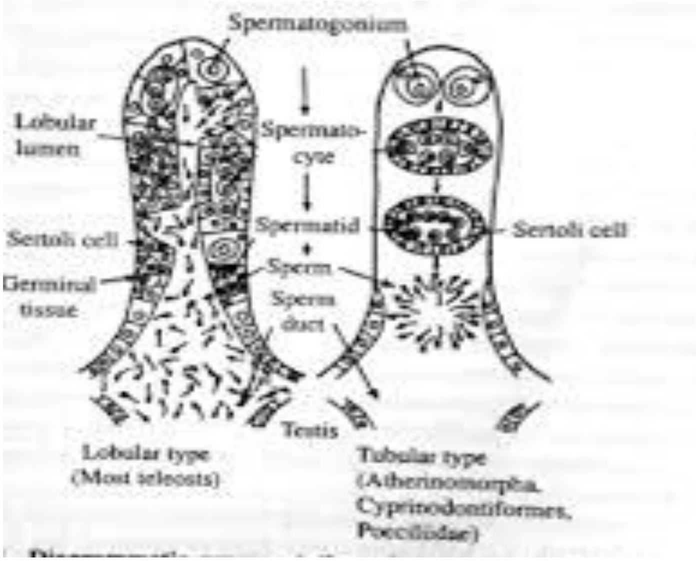


Fig.12.11: Types of testes structure in teleosts: Lobular type and tubular type (Courtesy: Nigahamma 1983, 1986)

During the growth-period, the resting germ cells become active and divide and are transformed into sperm mother cells or nests of spermatogonia. The spermatogonia are large, spherical cells containing a large round, centrally placed nucleus, having a distinct nucleolus. The cytoplasm of these cells does not take much stain. These cells multiply and give rise to primary spermatocytes which are small in size than the spermatogonia and possess dark stained nucleus. These undergo various stages of division during which the chromatin matter is visible as a fine reticulum and is later thickened on one side of the nucleus. The secondary spermatocytes arc smaller in size and their chromatin material is seen in the form of a thick clump. They last for a short period and divide to give rise to spermatids which are still smaller in size and possess that an elliptical nucleus that is deeply stained with hematoxylin. The spermatids give rise to sperms which are further reduced in size. The process of metamorphosis of spermatids into sperms is called 'spermiogenesis'. At the end of spermiogenesis, the seminiferous tubules are packed with sperm masses.

REPRODUCTIVE CYCLE (TESTICULAR)

Most of the fishes breed in one season every year (seasonal spawners) and some breed through out the year (year round spanwers). Seasonal breeders exhibit rhythmic changes in the structure and physiology of ovary and testes in different seasons. These changes in testis are demarcated into five phases:

1. Resting phase: Testis remain in immature state, seminiferous tubules are solid being filled with spermatogonial cells.

2. Preparatory phase: During this phase cell proliferation and 1st and 2nd meiotic division occur as a result primary spermatocytes, secondary spematocytes and spermatids are produced (spermatogenesis).
3. Mature phase: During this spermatids undergo further development and metamorphosis and develop into mature spermatozoa or sperm. The preocces of development of spermatozoa from spermatids is called spermiogenesis.
4. Spermiation phase: During courtship and mating process, male eject milt (spermatozoa in seminal fluid) out of its body through genital aperture to fertilize the eggs released by female. The seminal fluid is mostly secreted by the cells lining the vas deferens (sperm duct) and provide nourishment to the mature sperm. Both spermatogenesis and seminal fluid secretion are under control of gonadotropin of pituitary gland and male hormone testosterone.
5. Post spermiation phase: During this phase testis is characterized by the presence of evacuated seminiferous tubules.

OVARY

The ovary is a paired, elongated sac like structure lying in the abdominal cavity. The ovaries are suspended from the body wall by a pair of mesenteries called mesovarium. The mesovarium is richly supported by blood vessels and nerve fibres. There is a great variation in ovarian size even in the same individual. In a fully mature (gravid) female, the ovary occupies almost the entire abdominal cavity. The two ovaries are free at anterior but may be fused posteriorly (Fig. 12.10). Oviduct arises from the posterior part of each ovary. Both the oviducts unite and open to exterior either by a separate genital aperture or by a common urinogenital opening. The eggs are set free and pass into the oviduct through the ovarian funnel. In some forms (eg. Eel), however oviducts are absent. The ova are discharged by genital pores which may be regarded as degenerate oviducts (Parker and Haswel1, 1967). The colour of the immature ovary is pinkish or reddish while it is usually yellowish and granular in mature specimens. In viviparous fishes, the two oviducts have no connection with the ovaries. The oviducts in such forms are funnel shaped at the anterior most ends and posteriorly the two oviducts enlarge to form uteri where embryos develop. Histologically, the ovarian wall consists of three layers-the outer most peritoneum, the middle tunica albuginea made up of connective tissue and the innermost germinal epithelium. The germinal epithelium projects inwardly and gives rise to ovigerous lamellae which are the seat for the development of oocytes. The ovigerous lamellae contain large number of oogonia. Each oogonium passes a number of maturation stages and eventually develops into definite ova. This process of development is called oogonesis.

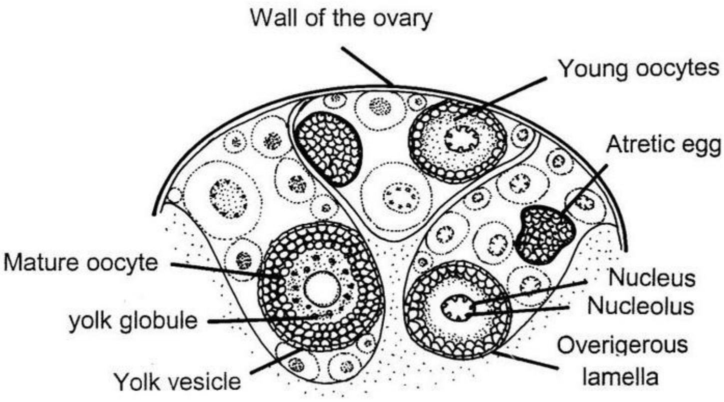


Fig. 12.12: Diagram of T.S. of Ovary

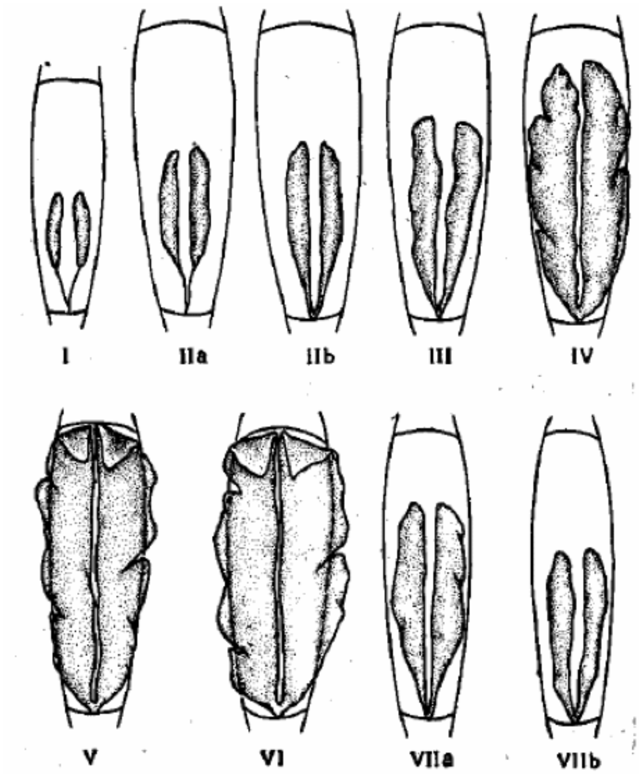


Fig.12. 13: Diagrammatic representation of different maturity stages of female

Stage I (Immature): The ovaries are soft cylindrical and almost translucent, pink or flesh-coloured. Sometimes due to post-mortem changes they appear purple in colour. The surface of the ovary is smooth with no distinct blood vessels. There is very little asymmetry in the size of the ovaries. The oviduct is fairly long and completely transparent with the result, the ovarian bodies look like detached stubs, short and plump. The entire length of the ovaries with their ducts occupies about or slightly more than 50% of the body cavity and measures up to about 35 mm of which the length of the ovary alone ranges from 10 to 25 mm. Their absolute weight may be about or below 0.25gm forming a maximum of 0.8% as relative weight. The ovaries are compactly filled with oocytes, not visible to naked eye. The oocytes are yolkless and transparent and measure up to 0.13 mm with the majority of them in the size range of 0.07 to 0.09 mm.

Stage II A (Developing Virgin) : Cylindrical, soft, translucent ovaries pink or flesh-coloured. Asymmetry is not quite distinct yet. Oviducts, thin and thread-like, are a little reduced in length and not more than 10 mm. The overall length of the gonads ranges from 30 to 35 mm forming 55 to 60% of body cavity. The ovaries alone measure about 20 to 25 mm in length and usually weigh around 0.4 gm, but may range from 0.3 to 0.6 gm. The relative weight is 1.0 to 1.5%. Majority of the ova are transparent with signs of yolk formation in some, which are mostly semi opaque but sometimes fully opaque with or without translucent periphery. However, even these do not appear as distinct grains to be easily recognised with naked eye. Maximum diameter of ova recorded is 0.30 mm with a large number of ova ranging in size from 0.15 to 0.18 mm.

Stage II B (Spent-resting) : The ovaries are dark-red or brownish red or deep flesh-coloured, having a collapsed and flattened appearance. External surface is wrinkled. The tunica is thicker and the Oviducts much wider and shorter than in the previous stage. The length of the organs is 30 to 45 mm occupying 55 to 60% of the body cavity. Their weight is commonly around 0.2 gm, forming less than 0.5% as relative weight. Occasionally, late spawners resting in January-February period may record a maximum gonad weight of about 0.4 to 0.5 gm with their relative weight of about 0.8%. Majority of ova are transparent, not visible to naked eye and measure 0.07 to 0.11 mm. A few scattered opaque ova may be present without transparent periphery and measure up to 0.15 mm. This stage is characteristically distinguished by the presence of clots of blood cells appearing as brownish masses in between the oocytes.

Stage III (Maturing): The ovaries are turgid, opaque and yellow in colour with granular appearance. Development of blood vessels is perceptible. The oviducts are very much reduced. Usually there is asymmetrical development in the size of the ovaries, either gonad longer than the other. This condition persists in the subsequent stages also. The ovaries occupy about 65 to 70% of the body cavity and measure from 35 to 50 mm. Their weight ranges from 0.8 to 1.5 gm, but usually it is below 1.0gm. The relative weight may accordingly vary from 2 to 4%. The maximum diameter of ova recorded is 0.54 mm. The size frequency distribution of ova normally shows one distinct mode of maturing ova around 0.35 to 0.40 mm, which are opaque with translucent periphery and visible to naked eye. In these ovaries, some semi-opaque ova with yolk deposition around the centre measure 0.15 to 0.17 mm and form a good percentage. Sometimes, ovaries advanced a little further but not entered into Stage IV show two modes of maturing ova, an advance one 0.42 to 0.47 mm and a minor one around 0.22 to 0.27 mm. Both sets of ova are opaque and are provided with translucent periphery.

Stage IV (Maturing) : The ovaries are compact, vascular with conspicuous blood vessels on the tunica and bright yellow in colour. Oviducts are not quite distinct. The organs almost extend to the entire body cavity forming 80 to 90% of the latter's length, with its own length varying from 45 to 65 mm. They weigh about 2.0 to 4.5 gm with an average of 3.0 gm, forming 4.5 to 7.0% as relative weight. The largest ova may measure about 0.67 mm and the size frequency polygons show two distinct modes, one Any where between 0.51 and 0.57 mm and the other around 0.27 to 0.34 mm. The former are completely opaque, while the latter are provided with translucent periphery.

Stage V (Mature) : The ovaries are orange-yellow in colour, fully vascular with prominent blood vessels ramifying on the surface. Tunica is very thin and bursts at slight pressure. Ovaries are very often more than the length of the body cavity with the anterior tips taking a loop down. Their normal length is 65 to 70 mm, but according to the size of fish may even extend up to 80 mm. Their average weight is 6.5 gm with a range of 5.5 to 7.5 gm. Relative weight ranges from 9 to 13%. Maximum diameter of ova observed is 0.82 mm. The distribution of ova shows two groups, an advanced mature one anywhere between 0.62 and 0.67 mm. and a maturing group around 0.35 to 0.47 mm. The ova of former group Present varying appearances; some are completely opaque, some provided with narrow or wide transparent periphery, some vacuolated, some partly Transparent and a few fully. Completely transparent ova have one big Oil globule or two-three smaller droplets of oil globule which measure from 0.054 to 0.109 mm and the other partly transparent and vacuolated ova have number droplets of oil globule. The ova of less advanced mode are fully opaque.

Stage VI (Running) : The ovaries appear as a sort of cream-coloured cellophane bags filled with boiled sago. At a slight prick, a gelatinous mass of transparent ova flows out, the tunica being so thin. Ova can be extruded on slight pressure externally on the flanks of the fish or even while handling. The ovaries measure more than 70 mm and fill the entire-space of abdomen cavity displacing the intestine to a narrow space in between the two ovaries- They may weigh from 8.0 to 12.0 gm, but ordinarily around 9.0 gm, forming 13 to 17% as relative weight. The largest ova are transparent and jelly-like reaching a maximum diameter of 1.2 mm, but the majority of these range from 0.80 to 0.91 mm in diameter with one or two oil globules very rarely cleaved into three which measure 0.091 to 0.127 mm. There is a significant number of medium-sized ova forming another distinct mode between 0.46 and 0.51 mm, which are completely opaque or provided with transparent periphery.

Stage VII A (Partially Spent): The ovaries are dark red in colour either throughout the length or only at the posterior half They are a bit flaccid and collapsed with slight wrinkles on the surface. The ovarian lamellae are clearly seen as book leaves especially at the posterior region indicating that the lamellae are not compactly filled with maturing ova and that some have been shed. The ruptured blood capillaries produce blood clots which appear as brownish or reddish masses. Blood capillaries penetrate deeply into the interior. Although the ovaries are shrunk in volume and reduced in breadth, they extend to 70 to 80% of the body cavity measuring 40 to 60 mm. Their weight ranges from 1.5 to 3.0 gm but is usually around 2.0gm, amounting to 2.5 to 5.0% as relative weight. The maximum diameter of ova is about 0.60 mm and the frequency distribution shows only one distinct mode anywhere within 0.35 to 0.51 mm. These ova are completely opaque but a few of these perhaps in the process of resorption are translucent with greyish yolk in the centre within which may be found a few droplets of oil-globule.

Stage VII B (Spent) : The ovaries are elongated, honey-coloured, bloodshot, flabby, limp and gelatinous with wrinkles on surface due to collapsed condition. The tunica is leathery and the wide oviduct is now Recognizable. The ovaries measure about 30 to 45 mm and occupy 55 to 60% of the body cavity. They almost always weigh around 0-5 gm with a maximum limit of 1.0gm, forming 0.6 to 1.5% as relative weight. Recently, spent fish have remnants of mature ova, measuring a maximum diameter of 0.47 mm, as resorbing and disintegrating opaque structures. The blood cells from ruptured capillaries appear as reddish clots. Sometimes, there may be a few scattered droplets of oil globule. The resorbing eggs are sometimes translucent in appearance, with the yolk in the form of small spherules, light grey or brownish in colour with man droplets of oil globule clustering around the centre. These ova form a small mode in the size frequency distribution around 0.27 to 0.31 mm. At a later stage, a few blood-coloured or brownish masses are seen which represent the unspawned ova broken down and covered up by the blood cells. In this state, the ovaries appear deep flesh-coloured. The rest are all immature transparent oocytes less than 0.25 mm in diameter.

12.5 GAMETOGENESIS, MODES OF REPRODUCTION, VIVIPARITY

GAMETOGENESIS

In the first stage of sexual reproduction, 'meiosis', a special type of that takes place in gonads prior to the a production of gametes, the number of chromosomes is reduced from a diploid number (2n) to a haploid number (n). During 'fertilization', haploid gametes come together to form a diploid zygote and the original number of chromosomes (2n) is restored in the offspring. Sexual reproduction involves the fusion or fertilization of gametes from two different sources or organisms.

Typically, a gamete or reproductive cell is haploid, while the somatic or body cell of the organism is diploid. A diploid cell has a paired set of chromosomes. Haploid means that the cell has a single set of unpaired chromosomes, or one half the number of chromosomes of a somatic cell. In diploid organisms, sexual reproduction involves alternating haploid (n) and diploid (2n) phases, with fusion of haploid cells to produce a diploid organism. Some organisms, however, exhibit polyploidy, whereby there are more than two homologous sets of chromosomes. Meiosis and mitosis are two diverse type of cell divisions. Mitosis occurs in somatic (body) cells. The resultant number of cells in mitosis is twice the number of original cells. The number of chromosomes in the daughter cells is the same as that of the parent cell. Meiosis occurs in reproductive or sex cells and results in gametes. It results in daughter cells with half the number of chromosomes present in their parent cell. Essentially, a diploid cell duplicates it's chromosomes, then undergoes two divisions (tetroid to diploid to haploid), in the process forming four haploid cells. This process occurs in two phases, meiosis I and meiosis II.

Fertilization involves the fusion of haploid gametes to give a diploid organism, which can then grow by mitosis. Thus, in sexual reproduction, each of two parent organisms contributes half of the offspring's genetic makeup by creating haploid gametes that fuse to form a diploid organism. For most organisms, a gamete that is produced may have one of two different forms. In these anisogamous species, the two sexes are referred to as male, producing sperm or microspores as gametes, and female, producing ova or megaspores as gametes. In isogamous species, the gametes are similar or identical in form, but may have separable properties and may be given other names. For example, in the green alga, Chlamydomonas reinhardtii, there are so-called "plus" and "minus" gametes. A few types of organisms, such as ciliates, have more than two kinds of gametes.

Sexually reproducing organisms have two sets of genes (called alleles) for every trait. Offspring inherit one allele for each trait from each parent, thereby ensuring that offspring have a combination of the parents' genes. Having two copies of every gene, only one of which is expressed, allows deleterious alleles to be masked. As with the other vertebrates, sexual reproduction is the overwhelming dominant form of reproduction. However, there are several genera of fish that practice true or incomplete parthenogenesis, where the embryo develops without fertilization by a male. Although vertebrates in general have distinct male and female types, there are fish species that are both males and females gonads(hermaphrodites), either at the same time or sequentially. For example, the amenone fish spend the first part of their lives as males and later become females, and the parrot fish is first female and then male. Some members of the Serranidae (sea basses) are simultaneous hermaphrodites, such as the *Serranus* and their immediate relatives, *Hypoplectrus* (the synchronoous hermaphroditic hamlets).

Fertilization may be external or internal. In the yellow perch, eggs are produced by ovaries in the female and sperm is produced by the testes, and they are released through an opening into the environment, and fertilization takes place in the water. In some live bearers, such as guppies and swordtails, females receive sperm during mating and fertilization is internal. Other behaviors related to sexual reproduction include some species, such as the stickleback, built nests from plants, sticks, and shells, and many species that migrate to spawn.

MODES OF REPRODUCTION

The ability to produce new living individual is a basic characteristics of all plants and animals. All reliable evidence indicates that new life comes only from pre-existing life; this is the process of biogenesis or reproduction. The different modes of reproduction can be classified according to the environment in which the embryos develop, and the sources of the nutrients supporting embryonic growth. These are mentioned into the following term:

OVIPARITY

Oviparity or egg laying refers to the situation where the development or the fertilized of egg occurs outside the body of the female. The young hatch when the egg envelope, shell or capsule is broken. Oviparous fish may be further categorized as being either ovuliparous or zygoparous. Ovuliparity refers to the release of ova from the reproductive tract of the female followed by fertilization or activation in the external environment. Thus, all organisms that have external fertilization and this includes most teleost are said to be ovuliparous. Zygoparity refer to the oviparous condition in which the zygotes (i.e. fertilized ova products of fusion between the eggs and sperm) are retained within the body of the female for a short period of time before being released into the environment. Obviously, zygoparous species display internal fertilization with their being a transfer of male sperm to the reproductive tract of the female. Zygoparous reproduction characterizes all skates some sharks and a small number of teleost.Irrespective of weather the fertilization of the eggs occurs internally or the egg yolk provides externally the nutrient for the developing embryos of oviparous species.

OVIPARITY IN FISHES

Amongst fish which reproduce by ovipartity, there are several groups.

Egg Scatterers: Fish which breed in this way either spawn in pairs or in groups. Males and females release milt (the sperm and spermatic fluid of the male) and eggs into the water at the same time. These mix together, fertilising the eggs. The fertilised eggs are broadcast (or spread) into the plankton column and float away in the current or sink to the bottom. No parental care is given, so large amounts of eggs are produced. It is easy to produce many eggs and because they are in the water, they don't dry out - necessary oxygen and nutrients aren't scarce. When theoffspring settle out of the plankton, they might be in totally new environments: this gives the young a chance to survive across a wide area. The main disadvantage of this method is that the fish must go through a larval stage before they transform into adults. In this larval stage, they are very vulnerable while they try to find food and avoid predators. Also, they may not find a suitable environment when they settle out of the plankton column. The survival rate for individual eggs is very low, so the parent has to produce millions of eggs.

Egg Depositors: These fish either lay eggs on a flat surface, like a stone or plant leaf or may even place them individually among fine leaved plants. The parents usually form pairs and guard the eggs and fry (young fish) from all danger. The Cichlids such as Koi are the best known species for this. Some Catfish and Rainbow fish are also egg depositors.

Nest Builders: Many fish species build nests. These might be a simple pit dug into gravel (trout do this) or an elaborate bubble nest. When they are ready to spawn, the fish may construct a nest by blowing bubbles, and they often use vegetation to anchor the nest. The male will keep the nest intact and keep a close eye on the eggs. The Gouramis, Anabantids and some catfish are the most common of this type.

Mouthbreeders: These are particularly odd, since eggs are fertilised externally, but raised internally. The females usually lay their eggs on a flat surface where they are then fertilised by the male. After fertilization the female picks up the eggs and incubates them in her mouth. Broods tend to be small, since by the time the fry are released by their mothers they are well formed and suffer minimal losses. The best known mouthbreeders are the African lake Cichlids.

Egg Buriers: The annual Killifish reproduce in this way. As the pools they live in dry out, the fish spawn, pressing their eggs into the mud. The pools eventually dry out completely, killing the adults, but the eggs remain safe in the dried mud. When it rains and the pool refills the eggs hatch and the cycle is repeated. Killifish eggs can survive for many years in dried out mud.

Ovoviviparity: In the ovoviviparous species the eggs usually develop within the uterus (modified oviduct) of the female. Fertilization of the egg occurs internally and the eggs are retained until hatching or beyond. The developing embryos do not receive any supply of foodstuffs from the female but must rely on the yolk of the egg for nutrition. This form of nutrition is known as lecthotrophy. The developing embryos must, however, rely on the female for supply of oxygen. During pregnancy the wall of the oviduct becomes enlarged and richly supplied with blood vessels.

Viviparity: Viviparous species have eggs, which develop either within the uterus (i.e. several species of shark), or within the ovary (i.e. teleosts). The developing embryos receive some nutrient supply from the female in edition to that provided as yolk in the egg. This form of nutrition is known as matrotrophy. The additional nutrient can be supplied in various forms. in some species of female secrets a nutrient-rich fluid which is taken up by the developing young has a form of 'soup'. In other species some form of 'placenta' may develop allowing a more direct transfer of nutrient from the blood of the female to the developing embryo. A distinction is sometimes made between viviparous animals in which the embryos derives nourishment from the mother's tissues as in most mammals and animals that are called ovoviviparous in which the embryo is nourished entirely by food stored in the egg, the hatching before being laid.

Viviparity in fishes: Fishes provide a key to understanding vertebrate viviparity in as much as the first viviparous vertebrates were fishes and they display the most diverse maternal fetal relationships of all the live bearing vertebrates. Viviparity occurs in three major fish groups: the chondrichthyans, the teleosts, and the actinistians. Although widespread, it represents the dominant mode of reproduction only among the sharks and rays. Approximately 420 of the estimated 600-700 species of chondrichthyan fishes are viviparous in contrast, only 510 of the estimated 20,000 species of teleost fishes are viviparous. The coelacanth, the only extant species of actinistian, is viviparous.

12.6 ROLE OF ENVIRONMENTAL FACTORS (PHOTOPERIOD, TEMPERATURE, RAINFALL, SALINITY) ON GONAD

The different stages of gonadal development are also aliened by their diet and environmental factors like photoperiod, temperature, rainfall etc. These environmental clues received by brain that stimulated to produce gonadotropin releasing hormone (GnRH) and it stimulate pituitary to r There are three primary factors that influence the events leading up to spawning: nutritional state of the female, physiological factors (hormones), and ecological factors.

Nutrition of the Female: The feeding condition of the mother can have an important effect on the final maturation of the eggs. Two examples from Hempel (1979) show that in some of the Atlantic herring populations spawning may occur only every other year if environmental conditions, particularly those affecting food supply, are poor. Also, it has been found in the laboratory that in Atlantic sole (Solea solea) no spawning occurred when the flatfish were fed a diet (mussels only) deficient in certain amino acids; however, when the flatfish were force-fed the missing amino acids they spawned, indicating the ovary had been unable to obtain the needed amino acids from maternal tissue when the nutrition of the female had been inadequate (Hempel 1979).

Physiological Factors: Hormones govern migration and timing of reproduction, morphological changes, mobilization of energy reserves, and elicit intricate courtship behavior. The pituitary is the major endocrine gland that produces gonadotropin, which controls gametogenesis, the production of gametes, namely sperm (spermatogenesis) and eggs (oogenesis), by the gonads. The pituitary also controls the production of steroids (steroidogenesis) by the gonads; once the gonads are stimulated by the pituitary they begin producing steroids, which in turn control yolk formation (vitellogenesis) and spawning. The control of spawning by the pituitary is often used in fish farming such as in the production of caviar from sturgeon (Acipenser spp.) where spawning is induced by injecting pituitary extract at a late stage of gonadal development, usually in combination with changes in temperature and light periodicity.

Ecological Factors: Often ecological factors are associated with timing so that food availability is optimal for the larvae. Some ecological factors important to spawning are temperature, photoperiod, tides, latitude, water depth, substrate type, salinity, and exposure.

Temperature: An important factor in determining geographical distributions of fishes. Although little is known about the mechanism by which temperature controls maturation and spawning in fishes, for many marine and freshwater fishes the temperature range in which spawning occurs is rather narrow, so that in higher latitudes the minimum and maximum temperature requirement for spawning is often the limiting factor for geographical distribution and for the successful introduction of a species into a new habitat. For example, Pacific halibut (Hippoglossus stenolepis) are found spawning primarily in areas with a 3-80C temperature on the bottom and therefore do not spawn in Puget Sound, although the adults are caught in the northern areas of Puget Sound. In fact, even in highly migratory tuna, spawning is restricted to water of specific temperature ranges.

Photoperiod and Periodicity: The day length (photoperiod), in some cases at least, is thought to influence the thyroid gland and through this the fishes' migratory activity, which is related to gonadal development (maturation). In the northern anchovy, by combining the effects of temperature and day length, continued production of eggs under laboratory conditions was brought about by keeping the fish under constant temperature conditions of 15^0C and a light periodicity of less than 5 hours of light per day (Lasker personal communication). In high latitudes, spawning is usually associated with a definite photoperiod (and temperature), which dictates seasonal pulses of primary production in temperate regions to assure survival of larvae. In low latitudes, where there is little variation in day length, temperature, and food production, other factors may be important such as timing with the monsoons, competition for spawning sites, living space, or food selection. Reproductive periodicity among fishes varies from having a short annual reproductive period to being almost continuous. There is a tendency for the length of the reproductive period to shorten with increasing latitude. Thus tropical fishes spawn nearly continuously, whereas subarctic fishes spawn predictably during the same few weeks each year.

Presumably times of spawning have evolved so larval development will coincide with an abundant food supply. Within spawning seasons, fish may spawn on a daily or monthly tidal cycle or on a diel cycle, or in association with some other environmental cue, such as a change in daylength, temperature, or runoff. A notable instance of spawning periodicity associated with the tidal cycle is the California grunion (*Leuresthes tenuis*), which spawns intertidally at the peak of the spring high tides (Walker 1952). Within species, spawning times may vary with latitude: Generally, in species that spawn as daylength increases, spawning occurs earlier in the year in lower latitudes than at higher latitudes. In species that spawn as daylength decreases, spawning takes place earlier in the year at higher latitudes than at lower latitudes.

Tides (moon cycles): The dependence of spawning on moon cycles in California grunion spawning on California beaches is an extreme example of external factors controlling reproduction in fishes. *Grunion* are adapted to spawning on the beach every two weeks in the spring during a new or full moon. Spawning is just after the highest high tide; therefore, eggs deposited in the sand are not disturbed by the surf for 10 days to a month later. Eggs will hatch when placed in agitated water (which simulates surf conditions). In Puget Sound, surf smelt (Hypomesus pretiosus) spawn year-round, except in March. Surf smelt deposit eggs at high tide in sand and gravel (but not necessarily at the highest tide). On the open ocean shores, spawning occurs at midtidal heights (for different subpopulations) (Dan Pentilla personal communication).

Latitude and locality: Pacific herring show a definite relationship between latitude and spawning time. Spawning is early in San Francisco (December, January); later in Washington State (February, March, April, May); and still later in Alaska (April, May, June). These fishes are perhaps of different, distinct subpopulations. In temperate waters a biomodal distribution of eggs is usually seen, which indicates discontinuous spawners. The smaller-sized mode represents resting eggs for a future spawning, and the larger mode represents maturing eggs (oocytes), which will presumably be spawned within the year. Temperate water fishes are also usually deterministic, which means all eggs to be spawned are determined at the start of the year. A polymodal distribution of eggs is typical of tropical areas and some temperate water fishes, which signifies continuous or serial spawners, and indicates several spawnings. A well-known temperate example would be Pacific sardine (Sardinops sagax), which spend 7 months spawning and 2 months developing/maturing (Clark 1934). Batch spawning has been described for northern anchovies (Laroche and Richardson 1983). Tropical spawners are usually nondeterministic, which means the eggs to be spawned are not determined at the start of the year but are produced throughout the year; however, nondeterministic can also represent the spawning potential for successive years, an example being the Atlantic cod (Gadus morhua), which will have several years' spawn in the ovary. In general, older fish usually spawn first and younger fish later, which means that a prolonged spawning period for a population may not be true for individual fish. Once a set of eggs is mature and hydrated, the female may release them all at once or in several batches. An example of releasing several batches is plaice (Pleuronectes platessa), where a single female two weeks after releasing one batch of eggs releases more eggs, and then three weeks later she releases the remaining eggs. Another example is the Pacific herring, which spawn once a year and females lay about 100 eggs per spawning act, which they repeat several hundred times over a few days (Hourston and Haegele 1980). In the lab, walleye pollock spawned an average of nine times in an average period of 27 days (Sakurai 1983).

It also needs mentioning that a long duration of the spawning season of a population cannot necessarily be taken as an indication of prolonged spawning of the individual fish. The prolonged period may be due to differences in spawning time between age groups since older fish tend to spawn earlier in the season. Furthermore, the coexistence of different spawning subpopulations must be taken into account, since winter and summer spawners may be distinct stocks, although shifts from one seasonal spawning pattern to the other may occur. An example of how unpredictable this can be is that certain Atlantic herring of low fecundity have been found to always spawn in the winter, regardless of whether they originated from winter or summer spawning (Hempel 1979).

Water Depth: Pacific herring spawn along beaches, marine grasses, and algae. Atlantic herring do not spawn along shore but in deeper water up to 200 m (the clearest difference between the Pacific and Atlantic herring, which are usually designated distinct species on the basis of genetic analysis). Of course fishes often spawn at one depth but live at different depths during other times of the year. For example, petrale sole (Eopsetta jordani), in which spawning occurs in a specific offshore area 300-400 m deep, were found by fishermen and eventually had to be protected with regulations to prevent overfishing (A.C. Delacy personal communication). **Spawning Substrate Type:** Pacific herring spawn on vegetation whereas Atlantic herring spawn on solid substrate (e.g., gravel). Lingcod spawn on rocks, pilings, and cracks in solid substrate; this species protects the egg mass. Some species such as buffalo sculpin (Enophrys bison) and plainfin midshipman (Porichthys notatus) spawn intertidally and will stay with the egg mass even when they are exposed at a low tide.

Salinity: Also a factor affecting spawning. There are varying salinities in many areas of estuaries. Some species will shift spawning sites because of salinity changes. Various degrees of mixing, precipitation, and freshwater runoff may alter spawning habits.

Exposure and Temperature: A clear example of shifting spawning sites in response to temperature and exposure is the black prickleback (*Xiphister atropurpureus*), where spawning is shifted from winter in protected areas to spring in exposed areas (Marliave 1975). The complex effects of lower or higher wave action and lower or higher temperatures on courtship, gonadal development, and spawning behavior that result in the spawning site shift.elease gonadotropic hormone (GTH).

12.7 GONADAL STEROIDOGENESIS AND ITS CONTROL

Sex steroids are involved in all aspects of the regulation of reproductive processes in vertebrates. Teleost fish produce several types of bioactive gonadal steroids, including estrogens, progestogens, androgens and numerous other steroids. Bioactive steroids are produced in specialized cells within the ovarian follicle (theca, granulosa) and the testis (Leydig cells). Depending on species, sex, reproductive stage and cell identity, these cells express an array of genes encoding steroidogenic enzymes that modify cholesterol and its derivatives. Steroidogenic cells may also express the gene encoding steroidogenic acute regulatory protein, which functions to transport cholesterol in mitochondria, the true rate-limiting step in steroidogenesis.

Gonadal steroidogenesis is pivotal to synchronize various reproductive stages including sexual development, growth and maturation. In all vertebrates including teleost, steroidogenesis is triggered by the mobilization of cholesterol by steroidogenic acute regulatory protein from outer to inner mitochondrial membrane. Thereafter, the entire process occurs in endoplasmic reticulum or mitochondria wherein various steroidogenic enzyme genes play a crucial role. The onset of steroidogenesis during sexual development in teleost is essentially regulated by differential expression of several transcription as well as steroidogenesis-related factors. More specifically, the role of dmrt, sox9, sox3, other sox forms, ad4bp/sf-1, wt-1, foxl2, ftz-f1, gata4, gsdf, Activator protein-1, fgfs and growth factors and steroidogenic enzymes such as cytochrome P450 aromatase (cyp19a1), hydroxysteroid 3β-dehydrogenase (hsd3b), hydroxysteroid 17β-dehydrogenase (hsd17b) have been well characterised. Recently, the role of pax2, THO complex (thoc), pentraxin (ptx) and few signalling molecules like wnt4/5 regulating teleostean steroidogenesis has been reported. In females, cyp19a1 appears to be critical as it converts androgens to estrogens during ovarian differentiation which suggests that estradiol-17β is indispensable for the event. Unlike females, males do not depend on testosterone for testicular determination, yet has a major role along with 11-ketotestosterone in testicular development and growth when compared to early testicular differentiation.

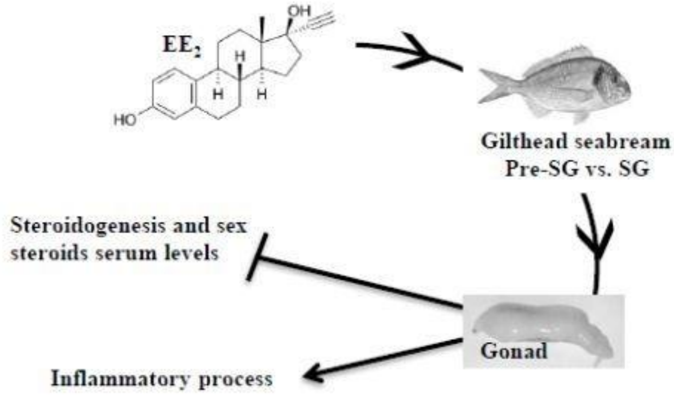


Fig.12.14: Effect of Estrogen

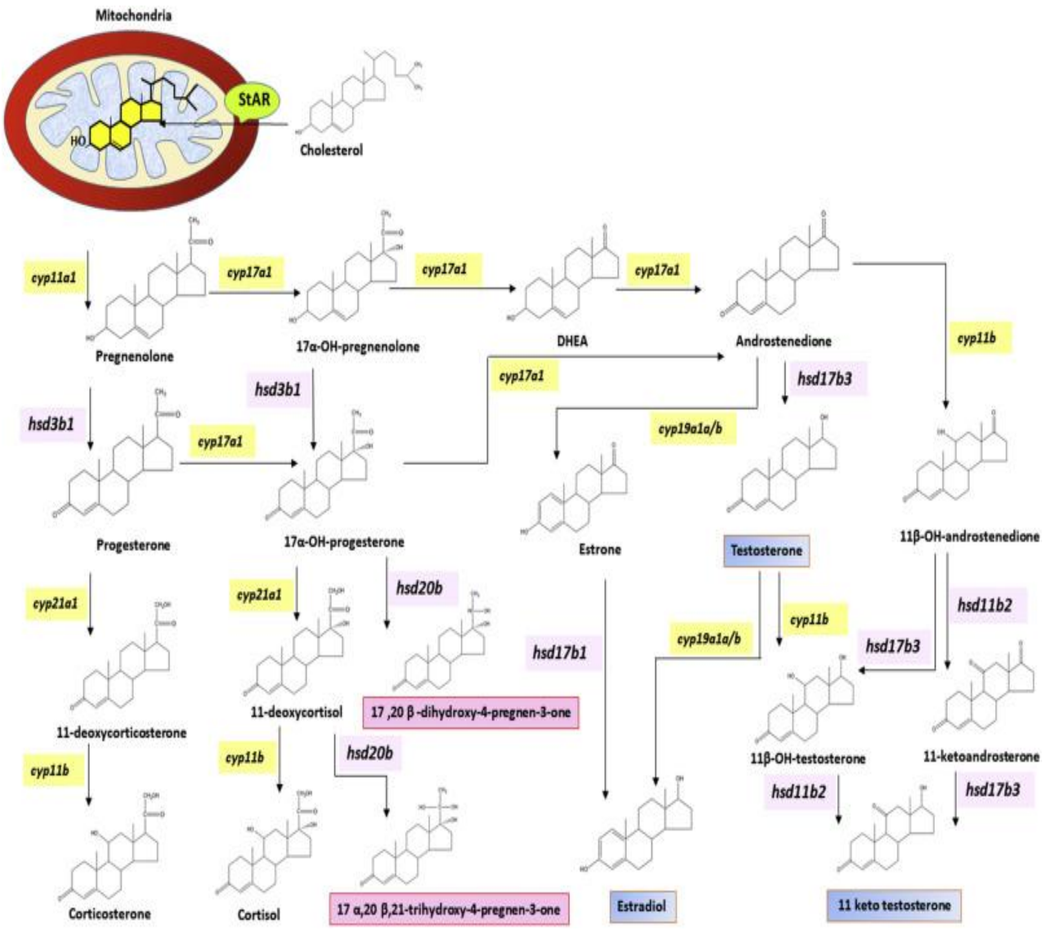


Fig.12.15: Pathway of Steroid Hormone Biosynthesis

12.8 REPRODUCTIVE STRATEGIES, ENVIRONMENTAL AND ENDOCRINE FACTORS REGULATING REPRODUCTIVE SYSTEM

Semelparity and **Iteroparity** refer to the reproductive strategy of an organism. A species is considered semelparous if it is characterized by a single reproductive episode before death, and iteroparous if it is characterized by multiple reproductive cycles over the course of its lifetime. Some plant scientists use the parallel terms monocarpy and polycarpy. In truly semelparous species, death after reproduction is part of an overall strategy that includes putting all available resources into maximizing reproduction, at the expense of future life. In any iteroparous population there will be some individuals who die between their first and second reproductive episodes, but unless this is part of a syndrome of programmed death after reproduction, this would not be called semelparity.

Semelparity: The word semelparity comes from the Latin semel, once, and pario, to beget. It is also known as "big bang" reproduction, since the single reproductive event of semelparous organisms is usually large, as well as fatal. A classic example of a semelparous organism is Pacific salmon (*Oncorhynchus* spp.), which lives for many years in the ocean before swimming to the freshwater stream of its birth, for laying eggs, and dying. Other semelparous animals include many insects, including some species of butterflies, cicadas, and mayflies, some molluscs such as squid and octopus, and many arachnids. Semelparity is much rarer in vertebrates, but in addition to salmon, examples include smelt, capelin, and a few lizards, amphibians, and didelphid and dasyurid marsupial mammals.

Iteroparity: The term iteroparity comes from the Latin *itero*, to repeat, and *pario*, to beget. An example of an iteroparous organism is a human-though many people may choose only to have one child, humans are biologically capable of having offspring many times over the course of their lives. Iteroparous vertebrates include all birds, most reptiles, virtually all mammals, and most fish. Among invertebrates, most mollusca and many insects (for example, mosquitoes and cockroaches) are iteroparous. Most perennial plants are iteroparous.

Based on reproductive strategies adopted by different fishes, they are categorised into three groups:

1. Non guarders (they do not guard their egg and larvae) are of two types

i) Open substrate spawners (lay eggs in open places)

ii) Brood Hiders (lay eggs in hidden places)

2. Guarders (Male or Female or both the parents guard the eggs and larvae after laying)

i) Substrate choosers

ii) Nest spawners

3. Bearers Non Guarders

i) External Bearers

ii) Internal Bearers

Reproduction is an essential component of life, and there are a diverse number of reproductive strategies in fishes throughout the world. In marine fishes, there are three basic reproductive strategies that can be used to classify fish.

The most common reproductive strategy in marine ecosystems is oviparity. Approximately 90% of bony and 43% of cartilaginous fish are oviparous. In oviparous fish, females spawn eggs into the water column, which are then fertilized by males. For most oviparous fish, the eggs take less energy to produce so the females release large quantities of eggs. For example, a female Ocean Sunfish is able to produce 300 million eggs over a spawning cycle. The eggs that become fertilized in oviparous fish may spend long periods of time in the water column as larvae before settling out as juveniles. An advantage of oviparity is the number of eggs produced, because it is likely some of the offspring will survive. However, the offspring are at a disadvantage because they must go through a larval stage in which their location is directed by oceans currents. During the larval stage, the larvae act as primary consumers in the food web where they must not only obtain food but also avoid predation. Another disadvantage is that the larvae might not find suitable habitat when they settle out of the water column. Oviparous Sharks and Rays do not have the advantage of producing high numbers of eggs, however they spawn eggs that have a large amount of yolk to provide nourishment as the embryo develops. These offspring also do not go through a larval stage, but are instead laid on the seafloor. The eggs of oviparous cartilaginous fish are often leathery and are attached to structures along the seafloor. These are often called “mermaid purses”.

Ovoviviparity is another reproductive strategy that occurs in most Sharks and Rays, as well as species of Rockfish. In ovoviviparous fish, the eggs are fertilized inside of the female. The eggs remain within the mother while they develop allowing for a greater degree of protection from predators and difficult environmental conditions than in oviparous fish. However, there is no direct nourishment provided by the mother. Another advantage of ovoviviparity is that the offspring are advanced in their development when they are born live, thus the juveniles are more likely to fend for themselves in the wild. A disadvantage of ovoviviparity is that fewer individuals are born and it takes more emery for the females to carry the eggs inside.

Viviparity occurs in some Sharks and Surfperches. Similar to ovoviviparous fish, internal fertilization and development occurs. However, the embryos receive direct nourishment from the mother, similar to the development of an embryo in mammals. Like ovoviviparous fish, the viviparous fish give birth to live young; however viviparous fish are fully advanced at birth allowing for a greater chance of survival. Viviparous fish are at a disadvantage if the mother dies because the offspring are likely to die and the mother is more vulnerable to predators when in labor.

ENVIRONMENTAL AND ENDOCRINE FACTORS REGULATING REPRODUCTIVE SYSTEM

Environmental factors like temperature, water condition, light, meteorological conditions etc are important factors controlling the reproduction of fish.

TEMPERATURE

i. There is an optimal temperature range for induced breeding of culturable fishes.
ii. Critical temperature limits exist, above and below which fish will not reproduce.
iii. Warm temperature plays a primary role in stimulating the maturation of gonads in many fishes. Temperature has a direct effect on gonads, regulating their ability to respond to pituitary stimulation and effects on primary synthesis and release of gonadotropins.
iv. Major carps breed within a range of temperature varying from 24-31°C.

LIGHT

i. Light is another important factor controlling the reproduction in fishes.
ii. Enhanced photoperiodic regimes result in early maturation and spawning of fishes like *Fundulus*, *Oryzias*, etc.
iii. *Cirrhinus reba* attains early maturation when subjected to artificial day lengths longer than natural day even at low temperature.

WATER CURRENTS AND RAIN

i. Rheotactic response to water current is well established in fishes.
ii. Fresh rain water and flooded condition are the primary factors in triggering the spawning of carps.
iii. The sudden drop in the level of the electrolytes in the environment caused by the heavy monsoon rains induces hydration in the fish and stimulates the gonads resulting in its natural spawning.
iv. Successful spawning of fishes has been induced on cloudy and rainy days, especially after heavy showers.

HORMONAL INFLUENCE

i. Gonadotropins have been found to increase during spawning and decrease afterwards.
ii. Due to the presence of females, there is an increase in gonadotropin level in males.
iii. FSH and LH have been reported to influence gonadal maturity in carps.

The majority of fishes breed at a particular time of the year and the seasonal reproductive cycle is precisely maintained by endocrine cycle. Environmental stimuli like photoperiod and temperature are presumably received by the brain which releases a decapeptide hormone, gonadotropin releasing hormone (GnRH). GnRH specifically binds to the receptor in the pituitary gonadotroph cells and stimulates the secretion of gonadotropic hormone (GtH). In fish GtH may be of one or two types. Circulatory level of GtH increases during gonadal development and maturation. GtH surge is highest during the breeding season when ovulation or spermiation occurs. GtH regulates ovarian and testicular function by inducing an exceptional steroid hormone which is 17α, 20β-dihydroxy-4-pregnen-3-one. However, there appears to be a shift in GtH function; it induces synthesis and secretion of estradiol-17β during previtellogenic phase which in turn induces vitellogenesis or yolk protein synthesis, while during post-vitellogenic phase GtH triggers the synthesis of 17α, 20β-dihydroxy-4-pregnen-3-one which is responsible for final maturation leading to ovulation or spermiation. The hormonal cascade of events is perfectly coordinated with the seasonal reproductive cycle of the fish to ensure spawning at a specific time of the year.

12.9 SEXUALITY: INTERSEX, BISEXUALITY, HERMAPHRODITISM

INTERSEX

Intersex conditions occur when exposure to chemicals disrupts the hormonal systems of an animal, leading to the presence of both male and female characteristics in an animal that should exhibit the characteristics of just one sex in its lifetime. In the case of smallmouth bass, male intersex fish are found with immature eggs in their testes, which indicates exposure to estrogenic and anti-androgenic chemicals. Intersex is regarded as the presence of male and female gonadal tissue simultaneously in an individual of a gonochoristic form (fixed-sex). The most frequently reported manifestation of intersex is the presence of single or multiple oocytes within the testes of sub-adult or adult males. However, several other manifestations, such as the presence of testicular tissue within ovaries or the feminization of male gonadal ducts, have also been documented . In terms of aquatic contaminants, intersex presents can vary according to the exposure and it could be a feminization process (i.e. the presence of oocytes in the testes or a masculinization process (i.e. The presence of spermatozoa with previtellogenic oocytes). Intersex also referred to as ovotestis, testis–ova or testicular oocytes (TO). It has received considerable attention recently in both the public and scientific studies. While, intersex is most commonly described as the presence of female germ cell oocytes within a male gonad predominantly. The abnormality of oocytes was observed in the male gonad and referred to as testicular oocytes (TO) in small mouth bass *Micropterus dolomieu*. Occasionally, these abnormalities are visible macroscopically but most often the gonad must be examined microscopically for clear detection. In fishes, those are normally gonochoristic, the presence of TO have been used as an indicator of exposure to estrogenic compounds and reported in a variety of wild fish species from various geographic areas (Blazer et al., 2007). Testicular oocytes are generally induced experimentally by exposure of fish species to estradiol, including medaka *Oryzias latipes rainbow* trout *Oncorhynchus mykiss* zebrafish *Danio rerio*, and the estuarine fish, Javanese ricefish *Oryzias javanicus*. In general, endocrine-disrupting compounds (EDCs) have the potential to perturb sensitive hormone pathways that regulate reproductive functions. In fish, this may result in decreased fertility and egg production in females, or lead to reduced gonad size or feminization of genetic male fish and also that male fish exposed to estrogenic compounds show induced production of vitellogenin, but the organismal significance of elevated vitellogenin levels has only been, for the most part, speculative.

BISEXUALITY

As a rule fishes are bisexual animals which means ovary and testis are found in two different individuals. Which is the prevalent kind; sperm and eggs develop in separate male and female individuals. Here sexual reproduction is the common method of reproduction. Sexual reproduction is a process of biological reproduction by which organisms give rise to descendants that have a combination of genetic material contributed by two different gametes, usually i.e. two different individuals, male and female. A gamete is a mature reproductive or sex cell. Sexual reproduction results in increasing genetic diversity, since the union of these gametes produces an organism that is not genetically identical to the parents.

SEXUAL DIMORPHISM: In a majority of fish species identification of sex by external examination is rather difficult, because there is hardly any difference in the external characters between the two sexes.However, there is also a number of species where sexual difference or sexual dimorphism is notuncommon. Sexual dimorphism is generally of two types-primary and secondary. Primary sexualcharacters i.e. ovary and testis and other associated structures are internal and cannot beascertained from outside. Thus, secondary sexual characters are very important as far as sexdetermination in fishes is concerned. Most of the secondary sexual characters are, however, in noway related to spawning and they usually meant for attracting the opposite sex.Sexual dimorphism in Indian major carps (catla, rohu and mrigal) is prominent during the breeding season. The male is generally having rough pectoral fins and comparatively slender body while the females are easily recognizable by their bulging abdomen and protruding vent. Infact, most of the carps exhibit similar features during spawning season.Size differences between the two sexes are common in most of the fish species. Generally females are larger than the males which may be due to the fact that the latter attain maturity earlier and they also have shorter life span.

Sexual Reproduction: Sexual reproduction is characterized by two processes: meiosis, involving the halving of the number of chromosomes to produce gametes; and fertilization, involving the fusion of two gametes and the restoration of the original number of chromosomes. During meiosis, the chromosomes of each pair usually cross over to achieve genetic recombination. Once fertilization takes place, the organism can grow by mitosis.

HERMAPHRODITISM

A hermaphrodite is defined as any individual organism that possesses both male and female reproductive organs during their life span. The main advantage of hermaphroditism is the assurance of a reproductive partner. Although hermaphroditism is quite common in invertebrates and plants, it is an exceedingly rare occurrence in vertebrates. Hermaphroditism in mammals and birds are almost always a pathological condition (often leading to infertility). Only in Perciforms (fish) does hermaphroditism occur naturally and in high frequency. Hermaphrodites are divided into two main categories: synchronous hermaphrodites, and sequential hermaphrodites. In the synchronous hermaphrodites, organisms possess both active male and active female reproductive organs at the same time. In sequential hermaphrodites, both male and female reproductive organs may be present, but only one is active and viable at any given time.

Synchronous or simultaneous hermaphrodites in reef fish are relatively atypical. A few Serranids (sea basses, e.g. *Serranus* sp.) and Hamlets are known synchronous hermaphrodites. During mating, one individual will lay eggs while another fertilizes the eggs, after which both will reverse roles and perform fertilization again. Synchronous hermaphrodites do not fertilize themselves; Self-fertilization does not promote genetic diversity, and can amplify genetic defects from parent to offspring. The interesting fact is most synchronous hermaphrodites form monogamous pairs.

Sequential hermaphrodites are so named because they are capable of transforming from one sex to another. Theses transformations entail a full conversion of gonads from one sex to another. The gonads of sequential hermaphrodites possess the genetic information to produce both male and female reproductive organs, but only the dominant gene is expressed at any giventime. Different cues - varying from species to species - may induce sex changes.

Sequential hermaphrodites are further categorized into two main categories: protogynous and protandrous. Protandrous hermaphrodites are those that develop into males first, then possibly to females. Protogynous hermaphrodites are the exact opposite, with juveniles first developing female reproductive organs that may possibly change into male reproductive organs in select circumstances. It should be noted that hermaphrodites do not necessarily have to change sexes, but by definition, are capable of this feat.

Protandrous hermaphrodites are the rarer of the two types. Pomacentrids (damselfish) are the most famous of these hermaphrodites. For example, clownfish of the genus Amphiprion live in communities that consist of one dominant female specimen and several smaller male (or asexual juvenile) specimens. If the female should be removed, a male will convert to a female, insuring a reproductive partner for the community.

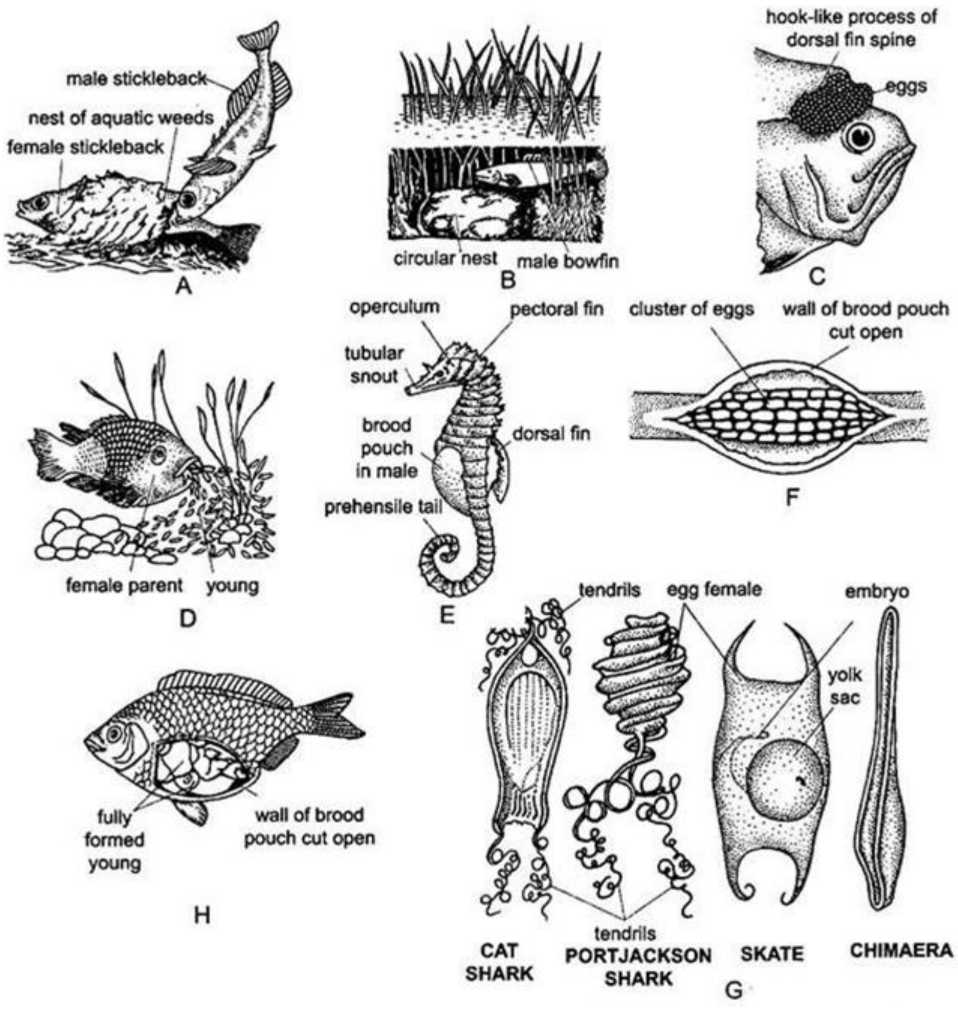
Protogynous hermaphrodites are most often haremic fish. These fish form monoandric harems comprising of 1 male overseeing numerous females for life. The two primary responsibilities of the male are to defend its territory against other conspecific males, and to court and fertilize females of its territory. If the male should die (either of natural causes or conflict-related mortality), the dominant female of the harem will undergo a sex change from female to male. This sex change may take as little as 5 days. The new male will then resume the full responsibilities of the previous male until he should die. Protogynous hermaphrodites that form harems include the wrasses of the genus Cirrhilabrus and

Paracheinlinus, Dwarf Angelfish of the genus Centropyge, and Anthias (e.g. *Pseudoanthias* sp.). Some protogynous fish do not form harems, but may form pairs. The dottybacks (*Pseudochromis* sp.) are presumably protogynous hermaphrodites that fall under this category. There are also sequential hermaphrodites that waver between sexes with no discernable order. The sexes of these fish are often determined by the ratio of sexes in an immediate community. These types of hermaphrodites include numerous gobies.

12.10 NEST BUILDING AND PARENTAL CARE

Parental care can be defined as an association between the parents and the offsprings, so as to increase the chances of the survival of the young ones, and in fishes it includes all the post-spawning care of the offsprings by the parents. Most fishes do not care for their eggs or youngs and leave the spawning grounds soon after fertilisation. The lack of parental behaviour is correlated with production of great numbers of eggs and sperms. But there are many fishes where definite parental care has been evolved. Various devices have been adopted to ensure proper development of the eggs into adults. One or both the sexes may participate in the process. These include selection of a suitable site, nest building and various other methods of protection of the larvae. Species which do not exhibit any special device for safety of the ova, generally produce a very large number of eggs to increase the chances of survival of at least a few of them. Eggs of many species possess various mechanisms for attachment to stones, pebbles or aquatic vegetation, so that they are prevented from being washed away with the current of water.

Nest Building: Some fishes prepare crude nests for egg laying. At first a suitable place for preparing the nest is selected and some species may defend the place till death. Males of many species like the Darters (*Etheostoma*), sunfishes and cichlids, prepare a shallow basin- like nest for laying eggs by females. The stones and pebbles are removed from such nest and male keeps close watch over the eggs till hatching. A few species, however, leave the nest unprotected. Many freshwater fishes prepare crude nest with aquatic vegetation where eggs are laid. *Protopterus* and *Lepidosiren* prepare deep hole into which the females lay eggs. Males protect the nest till development is complete. Amia calva (bowfin) prepare a crude circular nest among aquatic vegetation. The fertilised ova are protected by male who keeps guard over the nest till the young ones are hatched. The young ones are allowed to leave the nest in a body under the protection of father. Both the male and female of some cat fishes of North America prepare a crude nest in the mud for egg-laying. The nest is sometimes provided with protective cover of logs, stones, etc. Most interesting example is provided by the male stickleback *Gasterosteus aculeatus*, a small freshwater fish of North American lakes and ponds. The male fish actually builds a nest of dead aquatic weeds which are joined together by a sticky secretion produced from the kidneys. When the nest assumes a considerable size, the male makes a small tunnel. After the formation of tunnel and an elaborate courtship ritual, the male drags a mature female into the tunnel for laying eggs. After laying eggs, the female swims away and the male keeps watch over the fertilised eggs till development is over. In addition, foamy nest prepared by blowing of bubbles of air and sticky mucus are also encountered in many fishes. The bubbles of air and mucus adhere to form a floating mass of foam. The eggs are collected by the male in his mouth cavity and he throws them in such a way that the eggs can adhere to the lower surface of foamy nest. This type of caring for eggs is found in *Betta*, *Macropodus* and many other fishes.



Some interesting examples of parental care in fishes. A–Male stickleback (*Gasterosteus aculeatus*) muzzles female at the base of tail to stimulate her to lay eggs in a nest of dead aquatic plants; B–Male bowfin (*Amia calva*) guarding over circular nest; C–The male Australian *Kurtus* incubates eggs on its forehead; D–Very young of *Tilapia massambica* take refuge in female parents buccal cavity in times of danger; E–A male *Hippocampus* carrying brood pouch; F–Brood pouch of male *Syngnathus* opened to show eggs; G–Mermaids purses for eggs; H–Body cavity of *Cymatogaster aggregatus* cut open to show a fully formed young ready for hatching.

Mouth Cavity as Shelter: In some species, eggs develop within the mouth of the parent. In many cichlids, the female carries the eggs in her oral cavity. After hatching, the young fry do not leave the shelter for some time, and swim about in water very near the mouth, so that they can return to it in case of danger (found in *Tilapia*). In the cat fish, Arius the male carries the eggs and young ones in his mouth, and does not take food during this period.

Coiling Round Eggs: In butter fish, *Pholis* rolls the eggs into a rounded ball and then one of the parents remains on guard, possibly male, guards the egg-ball by coiling round it.

Attachment to Body: In *Kurtus indicus* (Perciformes) the male develops a bony hook projecting from the forehead and is supported by a special process of skull bone. The eggs are grouped in two bunches with the help of filamentous processes of the egg membrane. The eggs are attached to the hook of the forehead; in such a way that one bunch of eggs lies on either side of the head of the male, as he swims in water.

Formation of Integumentary Cups: In a cat fish, *Platystacus* of Brazil shows an interesting method of parental case. During breeding season, the skin of lower surface of the body of the female fish becomes soft and spongy. Immediately after fertilisation of the eggs, the female presses her body against the eggs in such a way that each egg becomes lodged in a small integumentary depression. Each egg is attached inside the cup by an inconspicuous stalk. The eggs remain in this position till hatching.

Development of Brood Pouches: In the pipe fish, *Syngnathus* and the sea horse, *Hippocampus* the eggs develop within the broad pouch of the male. The eggs are transferred into the brood pouch by the female and development takes place within the brood pouch.

Mermaid's Purses: Oviparous sharks (e.g., *Scyllium*) lay fertilised eggs inside the protective horny egg capsules or mermaid's purses, which remain anchored to the sea weeds by their long tendrils. The young hatch out after rupturing the egg case.

Viviparity: The highest degree of parental care is found in viviparous fishes where young develop within the oviduct of the female. A few species are viviparous, such as the dog-fish, Scoliodon and the surf fish *Cymatogaster aggregatus*. Both fertilisation and development are internal. Developing embryos are nourished mostly by a yolk sac placenta and the young are born with the characteristic of the adult. Viviparity provides maximum protection and represents the highest degree of parental case.

12.11 BEHAVIOUR AND COGNITION PATTERNS OF MIGRATION

Migration in many organisms is a very common phe- nomenon that occurs periodically in aquatic and ter- restrial environment. Migration is the orderly movement of animals from one place to another place in search of food, breeding habitat and better climate. Usually fishes live in a constant habitat and restrict their movement with in a particular territorial limit, but there are a few fish species which migrate from fresh water to sea water and vice versa. In nature adult fish migration is mainly for spawning and feeding. Fish migrate to new habitat, thousands of kilome- ters away from their home land. But in fishes in addition to seasonal migration there is also, diel migration. For a successful fish migration three things such as, motivation, orientation ability and energy storage and locomotory ability are very essentials.

Why Do Fish Migrate?

For survival fish migrate to new suitable habitat for feeding and reproduction, as the feeding and spawning grounds are separated in term of space and time. Some fishes migrate in ordered to escape from predators, while other dis- perses in all directions ensuring their expansion and survival According to three step model, fish start migration when:

(1) A fish achieve a certain threshold of body size or age depending on the growth rate and hatching date.

(2) Fish achieve certain physiological characteristics such as, energy accumulation, osmoregulation and smoltification. All these physiological functions are regulated by hormones; the most important one is thyroxin.

(3) The reception of exogenous and endogenous triggers that initiate migratory behavior

What is a Migratory Trigger?

A trigger by definition is anything that initiates a reaction or a process, by analogy to the metallic part of a gun moved by the finger to fire. In case of fish migration, trig- gers are environmental factors. There are several environ- mental factors that offer abrupt signals for fish to initiate migration.

Types of Migratory Triggers: There are two main migratory triggers, (1) extrinsic triggers and (2) intrinsic triggers, each containing sub-categories. Both extrinsic and intrinsic triggers actively participate in migration.

Extrinsic Triggers: In migratory biology, the influence of environmental fac- tors on migration is a very important theme. But this study is very challenging because, different environmental factors are correlated with one another, so it is very difficult to conclude that what factor really triggers migration. For example, there is a correlation between photoperiod and temperature in temperate climate. Some of the extrinsictriggers are as follow;

Water level, current and discharge: Water level is a migration triggers and is correlated to cur- rent speed and water discharge. This is why in some fishes migration is triggers by the arrival of monsoon season. Similarly during rainy season a change in water level and current speed occurs that is associated with both lateral and longitudinal migration. About in 26 fish species migrations are triggers by alteration in water level, discharge and water current. Some fishes are *Bangana behri; Paralaubuca typus; Pangasius conchophilus; Hemisilurus me- kongensis; Hemibagrus filamentus* (Bagridae);

Cyprinus carpio carpio etc. In some fishes migration for spawning occurs during seasonal floods when water level rises. Fishes from these flooded areas then move to stable water bodies as water level regresses. If in these areas due to climatic changes floods are delayed, migration will be also delayed.

Precipitation: In the tropics at the start of rainy season, precipitation in association with high water level triggers reproductive and breeding migration. It has been reported that upstream migration after dry season is triggered by the first rain fall. There are about ten species whose migration is linked with early rain falls. Some of them are *Tenualosa thibaudeaui* (Clupeidae); *Barbonymus gonionotus; Pangasianodon gigas; Mekongina erythrospila; Micronema bleekeri* (Siluridae) etc. This type of migration is also affected by the moon. Rain and floods, both trigger reproductive migration. Raining triggers migration in species which breed in calm water and floods trigger migration in species which breed in running water.

Lunar cycle: In certain fishes migration is linked with lunar cycle at a certain time of the year. These fishes sense the lunar cycle through tidal interface, gravitational force or visual cues, acting as direct or indirect trigger of migration. It has been noted that maturing adult eels migrate downstream while juvenile eels migrate upstream during the new moon. Migration in response to moon is affected by storm and falling atmospheric pressure. Migration in certain fishes such as *Cirrhinus microlepis; Paralaubuca typus* and *Tenualosa thibaudeaui* is triggered by the full moon. Migration in *Pangasianodon hypophthalmus* in initiated during or prior to the period of full moon.

Apparition of Insects: In certain areas such as Mekong River, fishers have observed that when fishes are about to start migration, there is the appearance of large number of mayflies and dragonflies. During this times these fishes comes to the surface and feed on these insects. Thus there is a link between fish migration and appearance of insect populations. Some fishes which migrate when blooms of insects appeared are *Pangasius pleurotaenia; Pangasius conchophilus; Paralaubuca typus* (Cyprinidae) etc.

Turbidity and Water Color: Alteration in water color and turbidity also triggers migra- tion. Some of the fishes migrate due to change in water colour and turbidity are *Tenualosa thibaudeaui* (Clupeidae); *Bangana behri; Pangasianodon gigas; Paralaubuca typus; Pan- gasius polyuranodon* etc.

Photoperiod: The intensity of light and photoperiod also influences migration of fishes. Similarly meteorological and sidereal influences affect the migratory responses. In a population to synchronize and start the activity of migration, pho- toperiod offers calendar information. Pacific lampreys (*Lampetra tridentata*) and Pacific salmon during spawning to synchronize the activity of migration, migration totally relies on photoperiod. At the same time other environmental factor such as, temperature is highly variable on a seasonal scale and is less reliable. Migratory activity synchronizes with daily (diel) changing between dark and light phase. These diel activities are divided into three categories- crepuscular, nocturnal and diurnal. This is not investigated yet that, whether this is the light level or true endogenous cir- cadian rhythm that affects the migratory activity. It has been reported that some fishes adjust their diel activities to changing light level. For example some nocturnal fishes become active on a cloudy day or when there is high turbidity.

Temperature: In fishes, temperature has also a role in synchronizing and triggering migration. Migration in response to temperature. Migration in response to temperature occur under two different conditions. When for a given population of fish, temperature reaches to a limit beyond the tolerance thresh- old. Such type of fish populations escapes from extreme heat and occupy new thermally suitable habitats. The best example is the sea lampreys. Secondly when the thermal requirements of fish population changes. For example, the thermal requirements for growth and reproductions are not the same. In the Laurentian Great Lakes, migration in *P. marinus* does not start until in the stream temperature exceeds to ~10^0C .

Oxygen Concentration: There are some fishes which migrate when oxygen concentration in the water become too low. For example, several centrarchids, three-spined stickleback etc.

Fish Density: Fishes can start migration only when sufficient numbers of fishes are waiting below the fault line. These fishes gath- ered and start migration.

Searching for Food: Availability of food is one of the most important factors that are responsible for large scale migration of many species of fish going out in search of feeding areas.

Intrinsic factors it include the followings;

Instinc: Migration is an innate and instinctive behavior and it is a genetic makeup that develops this instinct in the concerned species.

Physiological factors: The ripening of gonads, secretion of hormones and biological clock etc. are the biological factors influencing fish mi- gration. A number of hormones secreted by the pituitary gland such as prolactin, corticotrophin and growth hor- mone etc. are responsible for osmo and ion regulation in fishes during migration. The diadromous migrtation is associated with well-marked endocrine changes. Some of the hormones involved in migration are thoroughly discussed as follow;

Hypothalmo pituitary gonadal (HPG) axis: Gonadal maturation which is controlled by different hormones causes the fishes to migrate long distance from sea to rivers or vice versa. In Salmonids there are two different types of gonadotropin releasing hormone (GnRH), chicken GnRH-II (cGnRH-II) and sGnRH. During migration in chum salmon *(Oncorhynchus ketal),* the immunoreactivity and hybridization signals of sGnRH neurons in olfactory nerve (ON) and olfactory bulb (OB) were strong in the coastal sea but all these vanished or diminished on the spawning ground. Similarly on the spawning ground the immunoreactivity and hybridization signals of sGnRH neurons in telencephalon (TC) and preoptic area (POA) were stronger as compared to coastal area. SGnRH of the POA has a role in synthesis and secretion of gonadotropins, luteinizing hormone (LH) and follicle stim- ulating hormone (FSH) from the anterior pituitary gland. In both sexes gonadotropins are responsible for steroidogene- sis in gonads, and finally steroids stimulate gametes for- mation and its maturation. The hormones active in vitello- genesis are testosterone and estradiol-17β (E2), in spermat- ogenesis are ll-ketotestosterone (11KT) and testosterone but, in both sexes 17α, 20β-dihydroxy-4-pregnen-3-one (DHP) is active in gameto-maturation. In female salm- on fish during migration, the concentration of serum estra- diol-17β (E2) rises abruptly but falls rapidly when there is upstream migration. In these fishes the concentration of serum 17α, 20β-dihydroxy-4-pregnen-3-one (DHP) at the spawning ground increases sharply but is very low at the pre spawning ground. Similarly in male salmons, during the pre-spawning period the concentration of testosterone (T) and ll-ketotestosterone (11KT) increases rapidly but, were significantly decreased at the spawning ground except DHP. Similarly in lacustrine sockeye salmon *(0. nerka)* males increase T and 11KT is concerned with shortening of homing interval but increase serum level of DHP and reduces T is linked with reduction of homing percentage.

Hypothalmo Pituitary Thyroidal (HPT) Axis: Several scientish fish biologist suggested that at various stages of life hormones are responsible for olfactory learning and homing. They confirmed this by using artificial odors and found that juvenile coho salmon learn the odor of their homing area during a very sensitive developmental stage called Parrsmolt transformation (PST). During PST this sort of irreversible and unconditional learning is indicative of familial imprinting. Latter on it was proved this experimentally, that adult *Salmon* returned to the releasing site when reared at one area but released from another area during or prior to PST. It was also reported that, exposure of presmolt coho *Salmon* to any odor by artificially increasing the concentration of thyroxin were able to sustain the memories of that odor for a long time as compared to untreated group. There is a correlation between increased thyroxin level and increased sensitivity of olfactory sensations during PST. It was also found that as compared to parr; smolting masu *Salmon* (*O. masou*) olfactory epithelium has abundant of thyroid hormone receptors. This thyroxin in other vertebrates has also a role in the regulation of neurogenesis and peripheral olfactory system. HPT-axis is sensitive to various environmental factors such as photoperiod lunar phase; water flow rates temperature changes and exposure to novel water. All these environmental factors have a role in increasing the concentration of thyroxin level. During migration, *Salmon* fish have high concentration of thyroxin when compared to non-migrating salmon. Similarly downstream migration in kokanee *Salmon* can be induced by injecting high concentration of thyroxin. HPT activity is also affected during migration because, the migrants swimming rate increases, exposed to new environment where temperature, water flow rate and chemical composition are different. All these factors contribute to increase the production of thyroid hormone. High thyroxin level during migration has a role in migration and imprinting.

Insulin like Growth Factor-1 (IGF-1), Prolactin, Growth Hormone and Somatolactin: In *Salmon*, before starting migration the level of IGF-1 was high suggesting that IGF-1 stimulate the HPG- axis as a somatotropic signal. Similarly prolactin and growth hormone, in addition to osmoregulation has an important role in final maturation. Therefore growth hormone1receptor mRNA, prolactin mRNA and somatolactinlevel increases near the spawning ground.

METHODS OF FISH MIGRATION

A fish can make migration or migratory movements by several methods which are as follows;

1. **By Drifting:** In this method fishes are carried passively by water current.
2. **Random Swimming:** Fishes released from a point in a uniform environ- ment and spreading out in all directions, the process is called dispersal and leads to uniform distribution of the species.
3. **Oriental swimming movemen**t**:** In this method fishes move in a particular direction which may be (i) either towards or away from one habitat or (ii) at some angle to an imaginary line running between them and the source of stimulation.

TYPES OF FISH MIGRATION ON THE BASIS OF FOOD, SPAWNING, CLIMATE AND WATER CURRENT

Feeding Migration: Migration of fish in search of food and water is called feeding migration. This migration occurs because the supply of food in any habitat is not constant but, fluctuates from time to time. Fish in order to, survive and reproduce move to an areas with abundant of food supply. Some fishes are; cyprinids, salmonids, *Thymallus thymallus* and percids.

Spawning Migration: Migration for the purpose of spawning is migration in true sense and is also called spawning migration. This spawn- ing migration is more prominent as compared to feeding or climatic migration because of the aggregation of thousands of fishes to a particular habitat. These include salmonids, osmerids, cyprinids, castostomids etc.

Climatic or Refuge Seeking Migration: This type of migration occurs in response to harsh climatic conditions. For example; arctic and subarctic fishes migrate to separate refuge and feeding areas during their life cycle. These fishes include *Thymallus arcticus* and *Salvelinus alpinus.* Similarly *Anguilla anguilla* migrate in ordered to avoid ground ice, surface ice and cold water.

Contranatant Migration: Movement of migratory fishes against the water current is called contranatant migration.

Detanatant Migration: Movement of migrating fishes in the direction of water. Detanatant movement of adult salmon from sea to river is an example of Detanatant migration.

TYPES OF FISH MIGRATION ON THE BASIS OF DIRECTION

On the basis of direction Myers recognized three pat- terns of fish migration. They are as followed;

1. Diadromous migration
2. Potamodromous migration
3. Oceanodromous migration

1. Diadromous Migration: Fish migration between fresh water and sea water is known as diadromous migration. This migration is further classified into the following three types.

(a). Anadromous Migration: Journey of marine fishes from sea to fresh water for spawn-ing is called anadromous migration. Examples of such fish- es are *Salmon, Trout,* shad and *Lamprey* etc. Salmon travels thousands of kilometers in the sea and then several hundred kilometers into the fresh water rivers to reach the spawning grounds. They migrate in pairs. Black spots develop on the body of female *Salmon* and red spots on the body of male *Salmon* during the journey. The reproductive organs ripen and the alimentary canal shrinks. Females lay the eggs in saucer shaped nests. Then the male releases the sperms and the eggs are fertilized. After egg laying the spent fishes returns to their home. This upstream and downstream journey takes about one year. *Salmon* attain sexual maturity in about seven years. After attaining full sexual maturity they return to fresh water rivers for breeding purpose. During this migration, they came to many path and turns, water falls etc. but reached to their exact place of origin where they took birth seven years ago. After hatching young *Salmon* do not return to the sea until their salt secreting cells had developed.

(b). Catadromous Migration: Fish migration from fresh water to ocean for spawning is called catadromous migration. Fresh water eel is the best example of this type. There are sixteen species of fresh water eel. The yellow color of European eel represents the feeding and growing phase. When the color changes to sil- ver, it represents the breeding phase. 8-10 years old male and10-18 years old female eel prepear for migration. Their feeding stops, digestive tract shrinks and become function- less. Gonads covers the entire coelomic cavity, the eyes be- come large, lips thinner and the pectoral fins becomes more pointed. They travel 3-4 thousands kilomters. It is belived that the eel spawn at the depth of about 400-500 meters below surface at 16-17C^{0}. The parents die after spawning. Eggs hatched into a larva known as Leptocephalus. This larva is flat like leaf, transparent and tiny having large eyes with needle like teeth. It takes three years in reaching home. During this journry leptocephalous metamorphose into Elver’s larva and attain a length of about eight milimeter. Some other catadromous fishes are *Poramalosa richmondia, Myxus pelardi, Macquaria novemaculeata* etc.

(c). Amphidromous Migration: Migration of fishes from sea to rivers and vice versa, but not for breeding purpose is called amphidromous migration. This is mainly for food and change of environment. This travel may occur regularly at some definite stage of their life cycle. The only example is *Gobies*.

2. Potamodromous Migration: Fish migration from one place to another only with in fresh water is called potamodromous migration. Teleosts, cat fishes, trout, carps and perches show migrtaion pattern entirely within fresh water in search of suitable spawning grounds. This migration provides young ones suitable environment, abundant food and are free from predators.

3. Oceanodromous Migrtation: Long journey from one place to another with in sea is called oceanodromous migrtaion. Cod, Mackerels and Atlantic herrings take long journey in the sea from deeper hoter ocean water to the shallow colder shores for the pur- pose of spawning. This is during breeding season. After spawning they return to their original home.

Vertical Migration

Throughout the oceans, seas, and lakes, many species of fish and invertebrates are found to make diel (with a 24- hour periodicity) vertical migrations usually toward the surface at dusk and toward the bottom at dawn. The most plausible general explanation for such a regular event is that phytoplankton is to be found in the euphotic zone, near the surface. Herbivores must visit these strata in order to feed, and since they can feed in the dark (unlike most carnivores) the best time to visit the surface layers is at night, while by day they are safer dispersed in deeper wa- ter. The carnivores follow the migrations of the herbivores, feeding on them at dusk and dawn when they are in dense concentrations and before the illumination has fallen below the carnivores' visual threshold. Thus, vertical migration is driven by the need to feed and to avoid predators. In par- ticular, it is desirable for many larger species to avoid the surface waters by day where they are vulnerable to avian predators. Upward vertical migration at dusk seems to be triggered by falling light intensity and downward migra- tion at dawn by increasing intensity. In high latitudes, in the polar summer and winter, vertical migration is less evi- dent since there is a much reduced diel cycle of light. Vertical migration is also predictably influenced by bright moonlight (which tends to inhibit upward movement) and lunar or solar eclipses (which cause upward movements during the period of darkening.

Horizontal Migration

Daily vertical migrations are modulated by small-scale horizontal migration involved in feeding and predator avoidance. Reef fish may move on off the reef with a 24-hour periodicity, feeding by day and hiding at night (some "hide" by drifting in school-like aggregations away from the reef). Much larger seasonal horizontal migrations occur that are related to spawning and feeding. These are often depicted in the form of oscillatory triangular movements. For example, maturing Atlantic cod migrate to the

Norwe- gian coast to spawn in the spring. After spawning they re- turn to the offshore feeding grounds to recover. Herring in the North Sea moves southward in the early summer. Afterspawning they tend to drift eastward, overwintering in the eastern North Sea. In the spring they migrate offshore to the west and north and start to feed and mature for a repeat of the spawning cycle. Place in the southern North Sea have distinct spawning grounds but wider areas inwhich they feed and recover after spawning.

Speed of Fish during Migration

The average speed of fish during migration is three times the length of fish per second (body length × 3/ sec). For *Salmon* maximum speed during migration is 49 km day-1 but for grilse it is 47 km day^{-1}. For the same fish, speed is different because of variation in water velocity.

Distance Traveled During Migration

The distance covered by fish during migration varies from species to species and ranges from few hundred kilometers to few thousand kilometers.

Duration of Migration

It also varies from species to species and ranges from few months to years.

Anthropogenic Impacts on Migration

For several thousands of years humans have exploited fishes, during their migration. Humans constructed dams, and other barriers such as culverts and weirs which not only break the river or stream continuity but, also negatively affects migratory movements. These barriers not only physically disturb migratory movements but, also alter chemi- cals and physical properties of water, indirectly affecting their migrations. In some areas fish ways are present but, they are species specific and are very costly in terms of time and energy. Water pollution and toxicants alters chemicals and physical properties of water, so fishes are unable to identify their homeland as their home land odors are masked by pollutants. Pollutants and toxicants also, destroy olfactory, lateral line organs and negatively affect fish metabolism and swimming performance. All these human activities either causes fish mortalities or lead to delay or failure of migration.

Advantages of Migration

Migration has multiple advantages such as (1) better utili- zation of the new habitat and their resources. (2) one par- ticular habitat do not have enough food to support both adult and offspring’s, so due to migration they have sepa- rate feeding, breeding and nursery grounds. (3) Providing suitable climatic conditions for breeding and survival of the young's.

Disadvantages of Migration

It includes (1) Long journey is wasteful and many fishes get lost while migrating. (2) Numerous migrating fishes are eaten by predators. (3) Dams construction check migration and the concerned fish species become extinct.

12.12 SUMMARY

Nearly all fish reproduce sexually, and most species have separate sexes. Those without separate sexes avoid self-fertilization by producing sperm and eggs at different times. Each fish typically produces a large number of gametes. In most fish species, fertilization takes place externally. These fish are oviparous. Eggs are laid and embryos develop outside the mother's body. In a minority of fish, including sharks, eggs develop inside the mother's body but without nourishment from the mother. These fish are ovoviviparous. In many species of fish, a large group of adults come together to release their gametes into the water at the same time. This is called spawning. It increases the chances that fertilization will take place. It also means that many embryos will form at once, which helps ensure that at least some of them will be able to escape predators. Hermaphroditisms probably evolve under conditions where it is hard to find a mate, or where there is a differential size between the two sexes. It is interesting to note that sexes become exceedingly variable in many tropical fishes. Sometimes in the mature (gravid) population all the individuals are males (*Jenynsia*) at other times almost entirely females (*Molliensia*). If male is smaller than its female partner, larger proportion of male offspring may be expected, conversely if the female partner is equal to or smaller than the male, the offspring will be mostly females. Hermaphroditism generally occurs in the species belonging to Serranidae, Labridae, Scaridae and Sparidae. Individuals belonging to these families are mostly protogynous i.e. Females change to males as they grow under induced circumstances. The reverse change, protandry, from male to female is also known to occur as in polynemids. It has also been suggested that sex change can be triggered by sex-ratio threshold (i.e. If there is a great disproportion in the number of males and females). However, the physiological changes underlying sex reversal may be different in different groups of fishes (Shapiro, 1981). The including factors may be either social' or "environmental in the sex reversing fishes. In true hermamaphrodite fishes eggs and sperms develop in the same gonad and self fertilisation takes place in those fishes usually testes ripen first and the ovaries later. However, in some cases the gonads ripen in reverse order.

12.13 TERMINAL QUESTIONS AND ANSWERS

Q1. Discuss the parental care in fishes.

Q2. Write an explanatory note on reproductive strategy of fishes.

Q3. Draw the well labelled diagram of reproductive system of a teleost fish.

Q4. How the environmental factors affect the spawnning in fishes?

Q5. Explain the process of gametogenesis in fishess.

Q6. Explain hermaphroditism in fishes.

Q7. Discuss in detail about the role of gonadal hormones on reproductive behaviour of fish.

Q8. Explain the migratory behaviour in fishes.

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UNIT 13: ADAPTATIONS IN FISHES

CONTENTS

13.1 OBJECTIVES

After studying this module, you shall be able to learn and understand:

(i) Basic concept of adaptation

(ii) Colouration pattern in fishes

(iii) Sound producing oragans and their mechanism of action

(iv) Electric and luminescent organs and their significance

(v) Hill stream adaptation

(vi) Deep sea adaptations

13.2 INTRODUCTION

Adaptation is an important survival skill in all species.Adaptationsare changes an organism undergoes to fit different surroundings. If an organism is not able to evolve over time to suit its environment it may eventually become extinct. The natural surroundings in which an animal or plant is adapted to live is called its habitat.When ahabitat changes the species that is able to adapt best is most likely to survive. Fish, like other animals, have also adapted to live in different types of habitats. Most physical adaptations in fish occur in the mouth, body shape, coloration or method of reproduction. Various adaptations in these areas help fish survive in their habitats. Fish that forage on insects in streams have a much different mouth structure than fish that feed on other fish. The walleye, for example, has a large jaw with strong teeth to help it catch its food. Some fish have no teeth, only round vacuum-like mouths, these fish suck up organic material from the bottom or a stream or river. Body shape is also an important adaptation in fish. Fast moving fish have long torpedo shaped bodies to help them move though the water. Other fish that stay at the bottom of a stream or river have longer flat bodies. Most fish have fins; the location and shape of these fins vary from species to species. In general fish have a dorsal fin on their back and pelvic and anal fins on their undersides. They also have pectoral fins near the gills and a caudal fin as the tail. These fins can be prominent parts of the body structure or they can be, as in the case of the eel, practically unnoticeable. The size and texture of the scales also varies from fish to fish. Some, such as carp have large, noticeable scales; other fish have small scales, which are embedded in the skin giving the fish a smooth feeling. Another adaptation in fish and probably one of the most noticeable is the skin coloration. A fishes coloration can help it adapt to its' environment but the environment can also affect the skin color making it brighter or duller. Coloration can also be used as camouflage to help the fish hide from predators. For example, some fish such as pickerels and blue gills have vertical stripes to help them hide in vegetation. In some species, the male and female have different markings. Variation of patterns on the skin can be used to identify different sexes.

Some marine fish have the ability to produce light through bioluminescence. Most light-producing fish live in mid-water or are bottom-dwelling deep sea species. In fish, bioluminescence can occur two different ways: through symbiotic bacteria living on the fish or through self-luminous cells called photophores. Some species of deep sea angler fish (Lophiiformes) may use this light to attract prey, while others, like the Atlantic midshipman (*Porichthys plectrodon*), may use this light to attract mates. Many fish may use venom as a form of defense. Most venomous fish deliver the toxins through the use of a spine. Venomous spines are found in a wide variety of fish including stingrays, chimaeras, scorpionfishes, catfishes, toadfishes, rabbit fishes, and stargazers. Venomous spines can have poison glands along the grove of the spine, as with stingrays, or at the base of the spine, as in some catfish. While humans can be stung by a multitude of fishes, few species are life-threatening.

Elasmobranchs (sharks, skates, and rays) possess an electric sense system known as the ampullae of Lorenzini. This system consists of many tiny gel-filled canals positioned on the head of the fish. Through this system these fishes are able to detect the weak electric fields produced by prey. It is also believed that these fish can use this sense to detect the electric fields they induce when swimming through the earth's magnetic field, as a sort of compass. Since the fishes are able to generate the fields they detect, this is a form of active electro-orientation.

Some species of skates and rays also have electricity-producing organs. The electric rays have paired electric organs located on either side of the head, behind the eyes. With these organs, electric rays are able to shock and stun their prey. The skate's electric organs are located near the tail. However, these electric organs only produce weak electric fields not capable of stunning prey. Researchers believe that the skate's electric organs are used for communication and mate location.

The electric eel can also produce electric fields. These eels use weak electric fields for navigation, prey location, and communication. Additionally, these eels can produce strong electric fields to stun potential prey. The strength of the "shock" is related to the size of the eel, with larger individuals being able to produce more of a "shock."

13.3 COLOURATION

Majority of fishes are vividly and brightly coloured. Colouration is one of the most common phenomena found among the fishes. The enormous range of colours and patterns that produced in fishes is generally related to theirhabits. Normally fishes are darker on the dorsal and lighter on sides or ventral side. This gives them protection from above and below.

However, some fishes have uniform colouration as found in the gold fish, *Carassiu*s, which has brilliant colour all over the body. The bottom dwellers are often strongly and intricately coloured above and pale below. Variationin colour may be seen in a single fish. The trunk fish (Ostracion) has greenbody, orange tail and yellow belly with blue bands on the body.

The pipe fish, Sea horse and angler living in weeds, often exhibit colour andpattern similar to weeds. Sometimes they also develop leaf like or filamentous processes on the body. Mahasheer (*Tor tor*) has dark grey colour on the back with golden or reddish on sides and silver on the abdomen.

However, paired fins are yellowish or reddish. Colour differences in both sexes are quite marked in fishes. The males are generally brighter. Males ofsmall million fish, *Lebistes*, are variously coloured while females are of a single colour. The variation of colours in males is due to genetic factor of Y-chromosome. Another important feature is lack of pigment causes transparency in pelagic, free-swimming young's of many species. Similarly cave fishes living in total darkness, do not possess pigment and are colourless.

Sources of Colour: There are two main sources of colour production in fishes. These are chromatophores or bio-chromes and iridiocytes or iridiophores.

The Chromatophores: They are large and branched specialized cells. They are mostly present in the dermis, just beneath the epidermis or scales. They are also present around the brain and spinal cord. Chromatophores may be monochromatic, viz., and possess only one type of pigment, di or polychromatic. Cytoplasm of chromatophores contains different pigment granules, which are responsible for colour. These are flavines (yellowish green), carotenoides (yellow, red) and melanin (black and brown). Amalgamation of different chromatophores produces a wide range of colour, thus yellow and black.

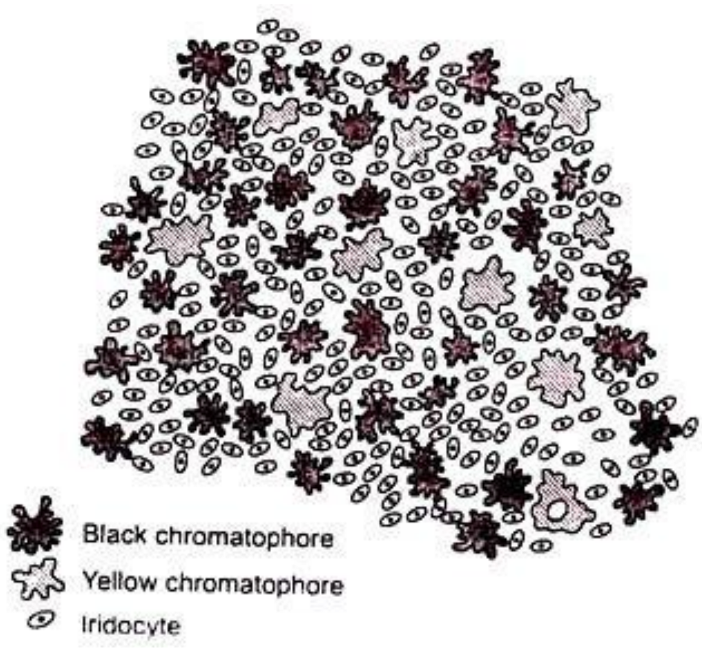

Fig.13.1: Chromatophores of a fish

Chromatophores inter-spread among one another to produce green or brown colour. Many fishes are able to change their colour of the body because of the migration of the pigment within the chromatophore. The pigment granules may disperse throughout the cell or aggregate in the centre to give different tone and pattern to the fish. There are four basic types of chromatophores based on colour of pigment granules present therein. These are erythrophores (red and orange), xanthophores (yellow), Melanophores (black or brown) and leucophores (white). The red and orange pigment granules of erythrophores and yellow pigment of xanthophores mainly consists of carotenoids. Fish obtain carotenoids through plant food. However, the black pigment of melanin is synthesized from amino acid tyrosine, under the influence of enzyme tyrosinase. Sometimes a brown pigment called eumelanin is also found in the chromatophores

Pigments of Chromatophore: Fish chromatophore contains following types of pigments:

Melanins: The melanin is the brown or black pigment derived from amino acid tyrosine. Melanin is synthesized usually in young melanophore and sometimes in adult melanophore. The first step of melanin synthesis is the oxidation of tyrosine to Dopa (3, 4-di-hydroxy-phenylalnine) under the influence of enzyme tyrosinase. Dopa further oxidized to Dopa quinone, which is polymerized to synthesized melanin. It is generally considered that higher tyrosinase level causes higher pigmentation in fishes.

Carotenoids: These are highly unsaturated hydrocarbon compounds containing carbon chain with ring structure at one or both ends. Carotenoid is found in xanthophores or erythrophores causing red or yellow colour. Carotenoid is insoluble in water but soluble in organic solvents, hence called as 'lipophores', the term widely used to denote xanthophores and erythrophores. It is reported that carotenoids cannot be synthesized in body of fishes and it is derived from food. In some species it comes from the pigment found in the yolk.

Ptridines: This is a similar compound to purines and flavins. Fishes are reported to have both coloured and colourless ptridines. Drosopterines including drosopterin, isodrosopterin and neodrosopterin are responsible for red colour. However, sepiapterins and iso-sepiapterins are yellow.

Purines: Guanine is a purine and is responsible for white or silvery tone in fishes. It is found in iridiocytes.

The Iridiocytes: They are also called as reflecting cells or mirror cells because they reflect light. The iridiocytes contain crystals of guanine, making them opaque and able to reflect light so as to produce either white or silvery appearance.This material is used in the manufacture of artificial pearls.

Iridiocytes when present outside the scales, produce an iridescent appearance and when they present inside them, forming a layer called argenteum produce a white or silvery appearance.

Colour Changes: Colour change is both short and long term phenomenon due to pigment change. It is both physiological and morphological phenomena. A morphological change is a slow process as it involves formation of pigment granules in cells. Physiological change is rapid (for a short period within a few minutes) andexhibits rearrangement of pigment granules in the chromatophores. Both of these changes occur due to visual and non-visual stimuli. The later involvenerve and hormones.

Physiological or Rapid Colour Change: In some fishes rapid change in colour occurs to match the changing surroundings. This type of colour adaptation is done by redistribution of pigment granules within the chromatophores. This type of colour change makes the fish inconspicuous over different backgrounds. The rapid colour change in fishes is known as cryptic or concealing colouration and may be of two types.

Assimilation with Background: In this type of colouration the fish harmonizes its colour to the background. The most common example of this type is pelagic laptocephalus larvae of eel, which is devoid of pigment. Sea horse and pipefish often have the colourthat resembles the seaweeds. The green colour of 'tench' resembles to that of surrounding by assimilation. Another interesting example of rapid colour change is seen in the flat fish (Pleuronectiformes). These fishes have remarkable matching power. When they are kept on checkerboard, they will, after a short period, develop almost same colour and pattern as that of background.

Disruptive Colouration or Breaking up the Outline of the Fish: The disruptive colouration is beneficial for concealment of fish. This is asort of camouflage. In this type of colouration the continuity of body adapting different colour and tone disrupts surface or shape. The disruptive outline of the body helps fish to conceal. Various types of spots, stripes, lines and bands of brilliant colours on fish body, break up the outline making the animal less conspicuous. Sometimes disruptive colouration is used as a special camouflage, in which different parts of the body is concealed. Thus that particular part of the body is prevented from recognition on sight. In Nassau grouper a horizontal coloured line is present in continuation with the body, which makes the eye inconspicuous. Similarly, a vertical line is present in the head of Jack-knifefish, to conceal the eye.

Sematic or Warning Colouration: Besides concealing, another kind of colouration is sematic or warning colouration. In this type fish is usually adopt striking pattern and colour thatreveals the animal then top conceal. This is of special significance for defence, as animal likely to attack are able to resemble the pattern and harmful effects previously associated with it. *Torpedo ocellata* has a prominent spot on electric organ for this purpose. Insome fishes obliterating colouration is adapted for concealment. The body of fish is countering shaded so that observer gets third dimension of the fish body, which reduces the visibility of fish.

Control of Chromatophores: The regulation and coordination of colour change in fish is generally by interaction of nervous and hormonal control.

Nervous Control: The chromatophores are supplied with nerve-fibres, which are responsible for contraction of pigment granules, resulting the paling of skin colour. The nerve fibres are post-ganglionic sympathetic fibres. In some fishes the nerve fibres of any part of skin are cut, the chromatophores of thatregion expand making area darker.

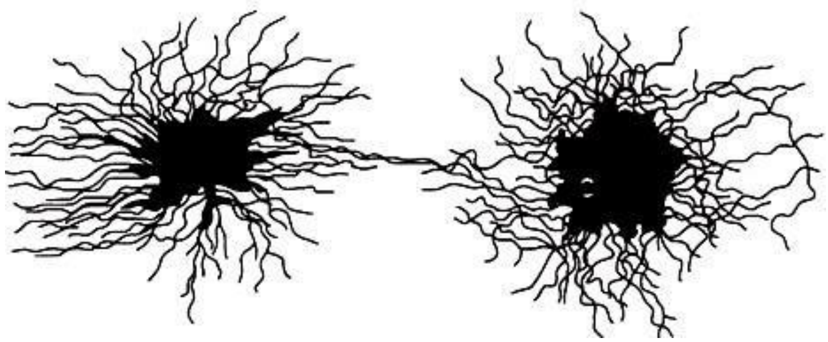

Fig.13.2: Nerves of the Melanophores of a Perch

Hormonal Control: The colour change is also controlled by the action of posterior lobe of pituitary. It is evidently observed in the Atlantic minnow *Fundulus* that hypophysectomy result in the lighter body colour than normal individual, due to contraction of chromatophores. The injection of pituitary extracts causes expansion of the chromatophores resulting dark colour of the body. It is believed that the two hormones of pituitary are responsible for colouration. The melanin dispersing hormone (MDH), i.e., intermedine causes darkening and the melanin-aggregating hormone (MAH) or W-substance causes paling of the body. It is evidently seen in Scyllum. Although the presence of MDH is found in many teleosts like *Anguilla* and *Fundulus.* In addition to pituitary hormones, adrenaline is also considered to control the action of chromatophore. It has chromatophore aggregating effect. Thyroxin is also believed to be responsible for colour change by effecting chromatophores.

Significance of Colouration: Colouration in fishes provides them power of adjustment with surroundings and also enables them to survive. The colour of fishes is used for concealment, communication, camouflage, sexual recognition and advertisement, warning or threat. Colouration also has taxonomic value. Different colour pattern in fish is often considered as character for distinction among species and subspecies. The specific pattern due to exact distribution of chromatophores is under genetic control. The colour pattern is also used in distinction of genera of some species like *Channa* and *Mystus*.

Factors Affecting the Colouration: There are various factors like temperature, light and stimuli which affect the functioning of the chromatophores. At low temperature chromatophores disperse causing darkening of the body while increase in temperature concentrates the chromatophores with substantial paling of the body. The light exerts its effect in two manners. In primary response the light affects the chromatophores by other sources then eyes. By secondary response chromatophores are affected by light through eyes. External stimuli like tactile or psychic type also influence colouration of fish. The psychic type also influences colouration of fish. The psychic type of stimuli contribute much for change in colour during mating behaviour of some fishes, when excited, shows psychological colour change in a short time, for example *Tilapia*.

Effect of Diet on Colouration: The colour of many fishes is also depends on their diets. Such types of diets may contain additional natural pigments to enhance colours of ornamental fishes. The carotenoid pigment found in most marine and a few freshwater invertebrates is astaxanthin. This pigment gives the characteristic colour to the flesh of salmon and is available in the diet of aquarium fish in shrimp and krill meals and salmon (fish) meal used as sources of protein in some feeds. Pure astaxanthin or canthaxanthin (synthetic astaxanthin) may also be added to fish feed to enhance red and orange coloration. These carotenoid pigments are often added to feeds for farm raised salmonand trout to give fillets a desirable red colour. Xanthophylls (yellow pigments) are found in corn gluten meal and dried egg that may be added tothe diet to enhance yellows. The ground petals of marigold flowers have also been used as a source of xanthophylls. The blue-green algae spirulina is a rich source of phycocyanin and may be added to a died to enhance blue coloration. The expense of supplementary pigments often limits the amount used in tropical fish feeds. These natural sources of pigments are in contrast to several methods routinely used to enhance colours of ornamental fish.

Effect of Water Quality on the Colouration: Water quality may also play a support role in determining the colour of ornamental fish. Degraded water quality increases stress on captive fish and may dull fish colours.A high quality biological filter and routine at least bi-weekly-water changeswill provide an environment enabling fish displaying their brightest colours. Feeding a varied diet rich in sources of pigments along with good water quality will ensure captive fish develop vivid colours.

13.4 SOUND PRODUCTION, ELECTRIC ORGANS AND LUMINESCENT ORGANS
(Species, location, structure, physiology and biological significance)

SOUND PRODUCTION

Fishes produce different types of sounds using different mechanisms and for different reasons. Sounds (vocalizations) may be intentionally produced as signals to predators or competitors, to attract mates, or as a fright response. Sounds are also produced unintentionally including those made as a by-product of feeding or swimming. The three main ways fishes produce sounds are by using sonic muscles that are located on or near their swim bladder (drumming); striking or rubbing together skeletal components (stridulation); and by quickly changing speed and direction while swimming (hydrodynamics). The majority of sounds produced by fishes are of low frequency, typically less than 1000 Hz.

The Swim Bladder and Drumming: Some fish, such as the sand seatrout (*Cynoscion arenarius*), produce sound by using muscles onor near their swim bladder (also called gas bladder).

Among the best-known sounds produced by fishes are those made by drumming ofthe swim bladder with the sonic muscle. The swim bladder is a large chamber of air located in the abdominal cavity in most bony fishes. The swim bladder serves many functions. It is used primarily for regulating buoyancy. Air gets into the swim bladder in one of two different ways, depending upon the species. In some species, there is a duct between the swim bladder and esophagus (the pneumatic duct) — this sort of swim bladder is called “physostomous”. These fish come to the surface and “gulp” air that is directed via this duct into the swim bladder. In other fishes, including all of those that live deep in the ocean, fishes have a special gas gland and rete mirabile, withinthe wall of the swim bladder, which is called a “physoclistous” swim bladder. The rete mirabile is made up of tightly packed capillaries, arranged so that those carrying incoming blood are adjacentto those carrying outgoing blood. This allows for filling of the swim bladder with gas from the circulatory system.Fishes such as drums and croakers (Family Sciaenidae) have sonic muscles attached to or near to their swim bladder. These muscles, the fastest contracting muscles knownin vertebrates, because the swim bladder to contract and expand at a rapid rate, thus creating drumming sounds. The majority of sounds produced in this way are short pulses with fundamental frequencies ranging from about 45 — 60 Hz (i.e., goliath grouper and black drum) to about 250 — 300 Hz (i.e., toadfish spp. and silver perch). Higher frequency harmonics produced by drumming are sometimes present above 1000 Hz (e.g., silver perch).

The sonic muscles of the toadfish are located along the lateral surfaces of the heart shaped swim bladder. Contraction of the sonic muscles produces a sound similar to a foghorn. In other species the muscles may be configured differently (such as anchored to the base of the skull) ormay be attached to another anatomical feature, which is then triggered to vibrate the wall of the swim bladder. For example, some marine catfishes possess a modified swim bladder mechanism, called the "Springfederapparat" or "elastic spring apparatus." Thin elastic bones function in sound production. Specialized sonic muscles on the upper surface of this elastic spring cause the vibration of the swim bladder. Drumming sounds have been described as thumps, purrs, knocks, and pulses all of which occur in different variations depending on the fish producing the sound. In this way fishes are able to produce species-specific sounds which can be used to identify them in recordings.

Stridulation: Stridulatory sounds are produced when hard skeletal parts or teeth are rubbed together, like the method used by crickets to make sounds. In fishes, stridulation often occurs during feeding when jaw teeth or pharyngeal teeth are gnashed together. Stridulation may be used intentionally to produce sound as a fright response or territorial display. Stridulatory sounds may be modified or amplified by the swim bladder. The component frequencies of stridulatory sounds range from <100 to >8000 Hz, while predominant frequencies are generally between 1000 and 4000 Hz. Stridulatory sounds influenced by the swim bladder have predominant frequencies well below 1000 Hz.

Weberian Ossicles

1. Meaning of Weberian Ossicles
2. Mode of Action of Weberian Ossicles
3. Functions

Weberian ossicles (Weberian apparatus): Structures found in bony fish belonging to the orders Cypriniformes and Siluriformes, and derived from the first four vertebrae. They form a link between the inner-ear region and the swimbladder, facilitating sound reception.

Meaning of Weberian Ossicles: The perilymphatic sac and the anterior end of the swim-bladder are connected by a series of four ossicles which are articulated as a conducting chain. Of the four, the tripus, intercalarium and scaphium actually form the chain, while the fourth one, claustrum lies dorsal to the scaphium and lies in the wall of posterior prolongation of the perilymphatic sac. The function of these ossicles is controversial. It is regarded that the Weberian ossicles either help to intensify sound vibrations and convey these waves to the internal ear, which help to understand the state of tension of air pressure in the bladder and transit changes of such pressure to the perilymph to set up a reflex action. Examples of fish species that produce sound by stridulation include marine catfishes and sea horses. In some species such as the grunts (Family Haemulidae), the swim bladder is hypothesized to function as a resonator to amplify stridulatory sounds. Marine catfishes (*Arius felis* and *Bagre marinus*) have specialized pectoral fin spines that make a stridulatory squeaking sound. The base of the pectoral fin spine is modified in these catfish. A partof the base, known as the dorsal process, looks like a ridged potato chip. Sound is created when the dorsal process of the pectoral fin is rubbed against the pectoral girdle. This is commonly heardby anglers who catch a sea catfish.

The northern seahorse is also known for producing stridulatory sounds. In these fish, clicking and/or snapping sounds are produced when bony edges of the skull and coronet, a crown- shaped plate on the fish's head, rub together. These sounds are possibly amplified by the swim bladder.

Hydrodynamic Sound: Hydrodynamic sound production occurs when a fish quickly changes direction and/or velocity. These sounds are extremely low frequency. These sounds are simply a by-product of swimming. It is possible that hydrodynamic sounds may be important to predator and prey interactions andcommunication. For example, it has been postulated that sharks can detect the low frequency hydrodynamic sounds emitted by smaller fishes. Therefore, schooling fishes may inadvertently attract a shark simply by the sounds produced during swimming.

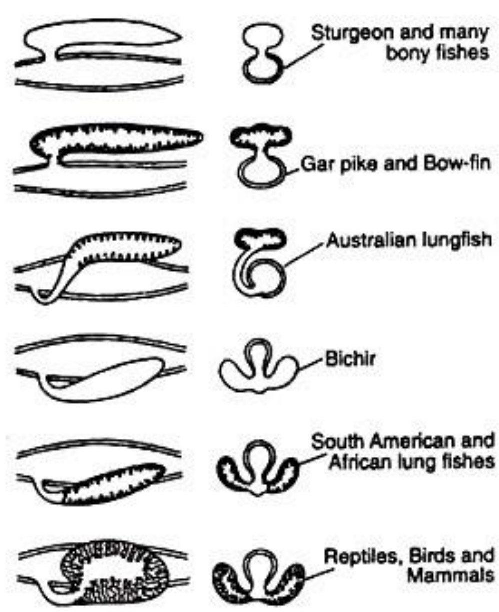

Fig.13.3: Relationship between the Swim Bladder and Lung with the Oesophagus in Some Tetrapods

There are various views regarding the actual process of derivation of these ossicles. It is believed that these ossicles are detached or modified processes of the first three anterior vertebrae. As regards the actual mode of origin of the four ossicles there are differences of opinion. The claustrum is regarded to be modified inter-spinous ossicle or modified spine of first vertebra or modified neural arch of first vertebra or modified intercalated cartilage or modified neural processof first cartilage. The scaphium is considered to be the modified neural arch of the first vertebra or modified rib of the first vertebra or derived from the neural arch of the first vertebra and also from the mesenchyme. The intercalarium is derived from the neural arch and transverse process of the second vertebra or from the neural arch of the second vertebra and also from the ossified ligament or from the neural arch of the second vertebra only. The tripus is formed from the rib of the third vertebra and the ossified ligament or from the transverse process of the third vertebra along with ossified wall of the swim-bladder or from the transverse process of the third vertebra and the ribs of third and fourth vertebrae.

Mode of Action of Weberian Ossicles:

1. Direct mechanical transmission of the vibrations.
2. Indirect system of transmission.

A change in the volume of the bladder causes its walls to bulge out of the opening and forces the ossicles forwards. In the indirect system of the cyprinoids, a backward movement of the posterior process of the tripus causes its anterior movement. The movements of the ossicles cause an increase in the pressure of the perilymph in the sinus in- par, which is conveyed to the sacculus. Thus, the vibrations of the gas bladder wall are transmitted to the ear by changes in tension. In direct system (Siluroids), the swim- bladder is enclosed in a bony capsule and protrudes through an opening in it for attachment with the tripus.

Functions of the Weberian Ossicles:

As Pressure Register: They are sensitive to changes in the volume of the swim-bladder due to variations in the hydrostatic pressure. Any change in the volume of the swim-bladder causes movements of the sinus impar. This is then conveyed to the sacculus through the endolymph of the transverse canal.

As Barometer: It is presumed that fish can detect variation in the atmospheric pressure through Weberianossicles.

As Auditory Organ: The ossicles transmit the vibrations of the bladder wall to the perilymph of sinus impar. Thevibrations reach the saccular otoliths via endolymph.

As Sound Locator: The vibrations received on the side of the bladder nearest the source are stronger than the otherside.

Luminous Organs or Photophore of the Fishes

A number of fishes especially marine species are known to produce characteristic light through their special organs called luminous organs. These organs are commonly found in fishes living in deep-sea where the sunlight ceases to enter. The luminous organs are absent in freshwater fishes. The most important function of bioluminescence is to illuminate surroundings for the purpose of camouflage, schooling and for recognition of movement of predators in the water. The luminous organs or photophores are special gland cells of the epidermis. Their distribution on the body type and adaptive value may vary in different species of fishes.

Structure of Luminous Organs: On the basis of anatomy of photophores they may be categorized in two types.

Simple Photophore: They are small in size, about 0.1 to 0.34 mm in width. It consists of light generating cells called as photocytes. Simple type may be provided with or without mantle of pigment. The lenses are formed by grouping of cells known as lenticular cells. The distal part of photocyte is provided with acidophilic granules. A layer of melanophres surrounds the photophore. Simple type of photophores is present in sharks. In Stomias the luminous organs are logged in gelatinous corium of the epidermis.

Compound Photophore: This type of photophores consists of additional structures like reflectors, pigmented mantle and sub-ocular organs. The latter one is a large organ deeply embedded in dermal tissue. The photocytes are arranged in the form of cords and bands. Photogenic tissue, pigment and reflector layers are provided with nerves and blood vessels. The photogenic tissues are found in the centre of the photophore and consist of two types of glandular cells.

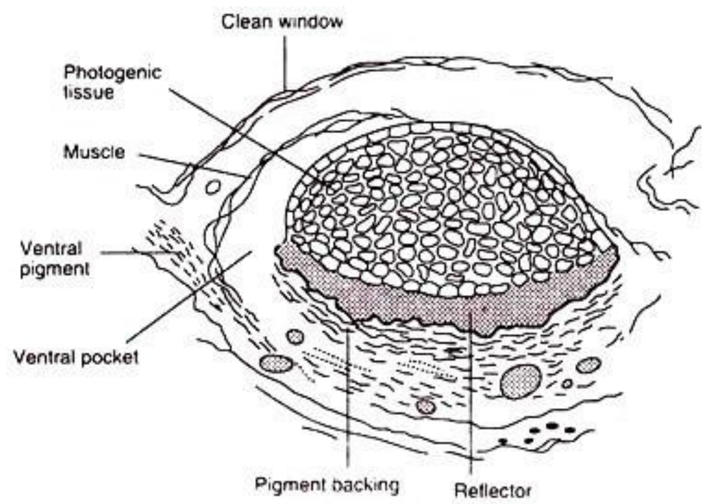

Fig.13.4: T.S. through a sub-ocular light organ of Astronesthes richardsoni

The mechanism of light production is peculiar in fishes and takes place the special sets of muscles present around the photocytes. When these muscles contract, they pull the outer surface of photophore downwards, causing brighter surface to be concealed. In contrast the relaxation of these muscles exposes bright surface of the photophores. In some species, movement of pigmented layer carries out concealing and rotating of photophores.

Types of Luminous Organs

On the basis of source of illumination it may be classified as follows:

Extra Cellular Luminescence: Light may be generated by luminous secretion from the glandular tissues. Extra cellular luminescent organs are found in a very limited species of fishes. Certain fishes like rat tails emit light by secreting extra cellular slime. Rat tails possess special glands near its anus, which secretes slime of sufficient luminosity.

Intracellular Luminescence: In this type the light is produced within the glandular cell or intrinsic photocyte. These luminous organs developed from the epidermis. Fishes ornamented with this type of luminous organs belong largely to the family of teleosts, i.e., Sternoptychidae (hatchet fish), Myctophidae (lantern fish), Halosauridae (Halosaurid eel), Stomiatidae (scaly dragon fishes), Brotulidae (Brotulus), Lophiidae (anglerfish) and Zoarcidae (eel pouts).

Bacterial Luminescence: In this type, symbiotic bacteria present in the photophore or luminous cell discharge light. Many different species are recognized particularly the genus photo-bacterium and achromobacterium have been isolated and grown in cultures. They are common on dead fish or spoiling meat. The biochemical step in bacterial luminescence is linked to the electron transport chain of oxidative phosphorylation, in which flavin mononucleotide ($FMNH_2$) from the electron transport chain reacts with an aldehyde (RCHO) to form a complex (luciferin) that is oxidized to an acid (RCOOH) with emission of light.

$$FMNH_2 + RCHO + O_2 \xrightarrow{\text{luciferase}} FMN + RCOOH + H_2O + 0.1/hv$$

Chemical Luminescence: It has been established that the glandular tissue secretes a chemical substance called as luciferin, which is an indole derivative consisting of tryptamine, arginine and isoleucine. Under the influenceof the enzyme luciferase, this substance is converted into oxy-luciferin and emits blue or blue- green light. Apogon, the *Parapriacanthus* is known to possess luminous glands containing crude form of luciferin and luciferase.

Control of luminous Organs: The function of light producing organs is controlled by the nervous or endocrine system.

1. **Nervous Control:** Several workers have reported that light production by the luminous organs is controlled by the nervous system, probably by the peripheral sympathetic system. The nerves innervate the phagocytes. The efferent nerves enter the photogenic cells and activate them.
2. **Hormonal Control:** It has been reported that some fishes have hormonal control on the photophores. Endocrine gland like supra renal activate them. Adrenalin or noradrenalin is known to control light emission from the photophores.
3. **Mechanical Control:** The muscles present beneath the photophores contract and rotate the photophores in such a way that they get concealed. Thus fish is prevented from illumination specially when in danger.

In *Photoblepharon palpebratus* the ventral part of luminous organ has a fold of black tissue. This fold can be drawn over the photophores and conceal the light. In some fishes the light production is also supposed to be influenced by the movement of pigment in the chromatophores.

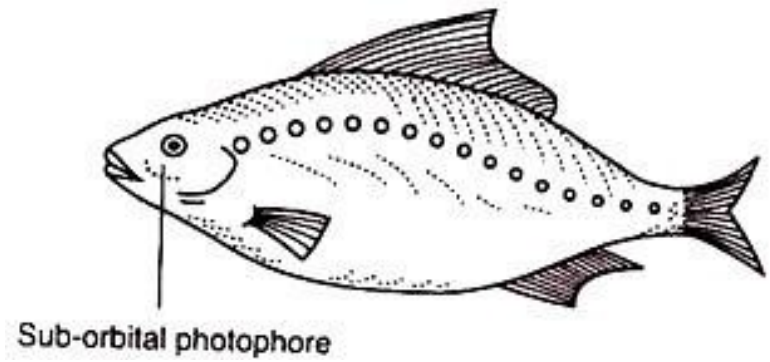

Fig.13.5: Light producing organs of Photoblepharon

Biological Significance of Luminous Organs: This is useful in variety of ways in marine fishes especially in deep-sea fishes.

Illuminates Surroundings: Some fishes utilize their luminous organs to illuminate their surroundings in the event of dimness. Thus they become able to search their prey in the dark waters. Some species (stomiatoid) are able to emit beam of light from the specially designed luminous cheek organ to catch the small creatures like planktons. The cheek organs of *Anamalops* produce light like a torch.

As Defensive Device: Many fishes produce sudden flash of light from their luminous organs, which helps in diverting the attention of their predators. The emission of light facilitates an escape of fish by puzzling theenemy. *Alepocephalidae* produce a glowing spark, which confuses the predator for a spur of moment, and help the fish to escape.

However, some fishes use luminous organs to enable them inconspicuous. In doing so they illuminate their ventral surface that makes them inconspicuous against lighted background above.

As a Warning Signal: A number of fishes use its luminous organ to warn the predators. For instance, the midshipman *Porichthys* that possesses, a toxic sign, flashes light when it is attacked by a predatory fish and avoids the danger.

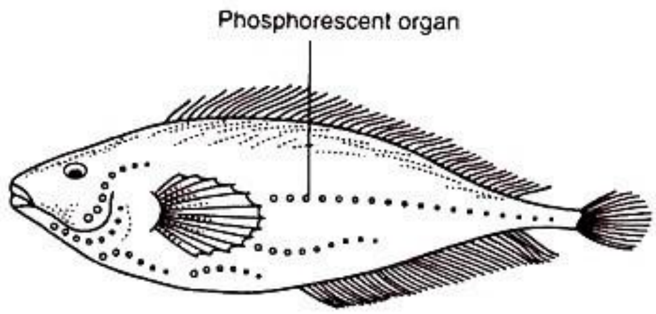

Fig. 13.6: Light producing organs of Porychthyes

Recognizing Own Species: Every species has a unique arrangement and distribution of photophores on their body, which help the fish to recognize species of same type and thus help in schooling behaviour. The luminous organs are also helpful in recognizing the mates for courtship, as the light organs may be different both in male and female. Male lantern-fish has one or many photophores present above but in the female possess it below the caudal peduncle. In some species the size of luminous organ is different in both sexes. For example in many species of melanostommiatidae, the postorbital luminous organ is larger in the male and smaller in the female.

ELECTRIC ORGANS AND ELECTRORECEPTORS

Electric organs are masses of flattened cells, called electrocytes, which are stacked in regular rows along the sides of certain fishes, e.g., the electric eel of South America. The posterior surface of each electrocyte is supplied with a motor neuron.

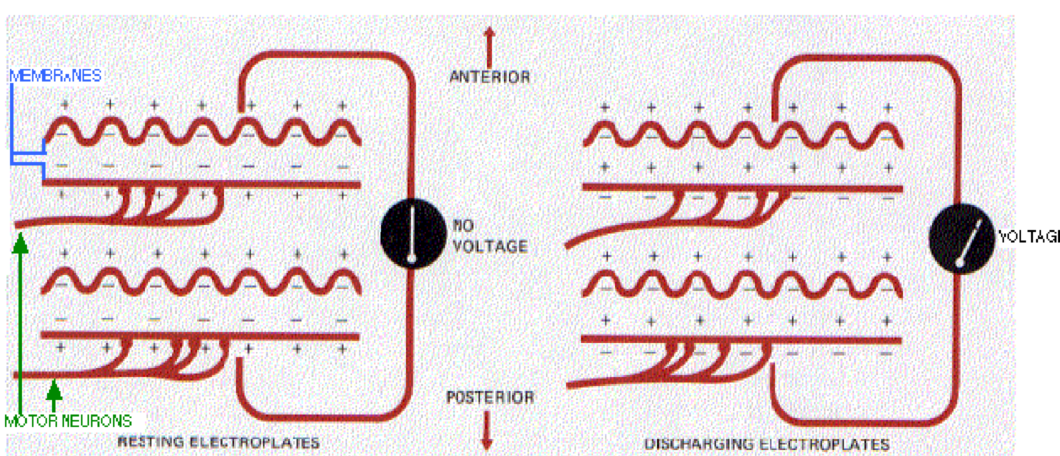

Fig.13.7: Electric Organ of fish

At rest, the interior of each electrocyte, like a nerve or muscle cell, is negatively charged with respect to the two exterior surfaces. The potential is about 0.08 volt, but because the charges alternate, no current flows. When a nerve impulse reaches the posterior surface, the inflow of sodium ions momentarily reverses the charge just as it does in the action potential of nerves and muscles. (In most fishes, electrocytes are, in fact, modified muscle cells.) Although the posterior surface is now negative, the anterior surface remains positive. The charges now reinforce each other and current flows just as it does through an electric battery with the cells wired in "series".

With its several thousand electrocytes, the South American electric eel (*Electrophorus electricus*) produces voltages as high as 600 volts. The flow (amperage) of the current is sufficient (0.25–0.5 ampere) to stun, if not kill, a human. The pulse of current can be repeated several hundred times each second. Powerful electric organs like those of the electric eel are used as weapons - to stun prey as well as potential predators.

The Mechanism: While exploring its environment, the eel emits a continuous series of low-voltage discharges. Periodically it interrupts these with a discharge of 2 or 3 high-voltage pulses. These cause nearby prey, e.g. a fish, to twitch. Within a tiny fraction of a second (20–40 ms) of detecting the twitch, the eel unleashes a volley (~400 per second) of high-voltage discharges that stun the prey enabling the eel to capture it.

Remarkably, both the twitch response and the immobilization are triggered by the prey's own motor neurons. A pair of pulses induces a brief contraction while a volley of discharges induces tetanus.

Although action potentials in the prey's motor neurons were not measured directly, two pieces of evidence support this mechanism.

1. The responses remained intact even when the brain and spinal cord of the prey were destroyed thus eliminating the possibility that the prey was relying on a sensory→cns→motor reflex.
2. Curare, which blocks the transmission of action potentials across the neuromuscular junction, did block the prey's responses.

Weak Electric Organs: The electric organs of many fishes are too weak to be weapons. Instead they are used as signaling devices. Many fishes, besides the electric eel, emit a continuous train of electric signals in order to detect objects in the water around them. The system operates something like underwater radar and requires that the fishes also have electroreceptors (which are located in the skin). The presence of objects in the water distorts the electric fields created by the fish, and this alteration is detected by the electroreceptors. Electric fishes use their system of transmitter and receiver for such functions as:

- navigating in murky water and/or at night
- locating potential mates
- defense of their territory against rivals of the same species
- attracting other members of their species into schools

Electroreceptors: Electroreceptors are also found in some nonelectric fishes and in some amphibians. Even the duckbill platypus, a mammal, has electroreceptors (located in its bill). With these it can detect the weak currents created by the muscle activity of its prey (e.g., small crustaceans) as it noses around in the muddy bottom where it feeds.

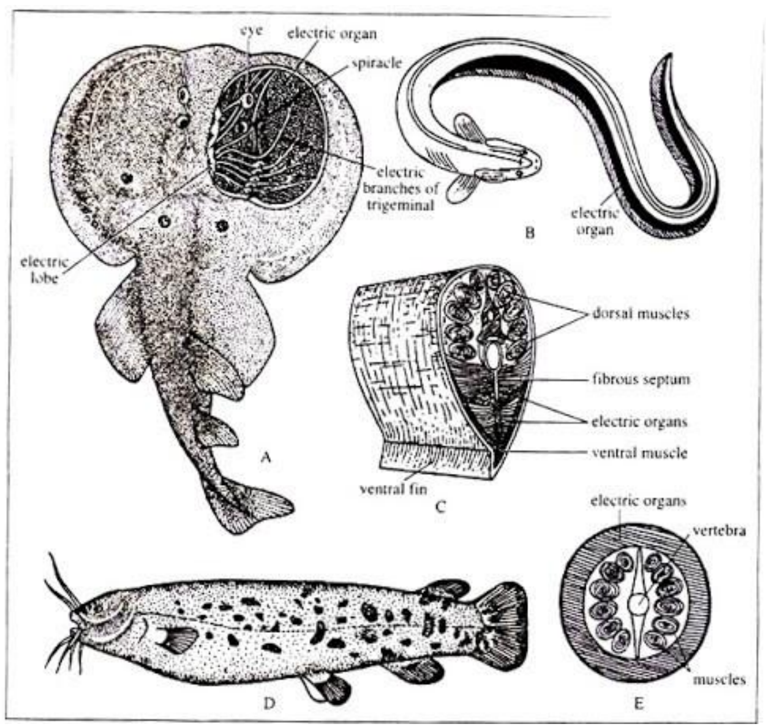

Fig.13.8: Electric Organ of Different Fish; A. Torpedo, B. Electrophorus electricus, C. T.S. of electric organ of Electrophorus electricus, D. Malapterurus & E. . T.S. of electric organ of Malapterurus

13.5 ADAPTATION IN DEEP SEA

Deep-sea fish are fish that live in the darkness below the sunlit surface waters that is below the epipelagic or photic zone of the sea. The lanternfish is, by far, the most common deep-sea fish. Other deep sea fishes include the flashlight fish, cookiecutter shark, bristlemouths, anglerfish, viperfish, and some species of eelpout. Only about 2% of known marine species inhabit the pelagic environment. This means that they live in the water column as opposed to the benthic organisms that live in or on the sea floor. Deep-sea organisms generally inhabit bathypelagic (1000–4000m deep) and abyssopelagic (4000–6000m deep) zones. However, characteristics of deep-sea organisms, such as bioluminescence can be seen in the mesopelagic (200–1000m deep) zone as well. The mesopelagic zone is the disphotic zone, meaning light there is minimal but still measurable. The oxygen minimum layer exists somewhere between a depth of 700m and 1000m deep depending on the place in the ocean. This area is also where nutrients are most abundant. The bathypelagic and abyssopelagic zones are aphotic, meaning that no light penetrates this area of the ocean. These zones make up about 75% of the inhabitable ocean space. The epipelagic zone (0–200m) is the area where light penetrates the water and photosynthesis occurs. This is also known as the photic zone. Because this typically extends only a few hundred meters below the water, the deep sea, about 90% of the ocean volume, is in darkness. The deep sea is also an extremely hostile environment, with temperatures that rarely exceed 3 °C (37.4 °F) and fall as low as −1.8 °C (28.76 °F) (with the exception of hydrothermal vent ecosystems that can exceed 350 °C, or 662 °F), low oxygen levels, and pressures between 20 and 1,000 atmospheres (between 2 and 100 megapascals)

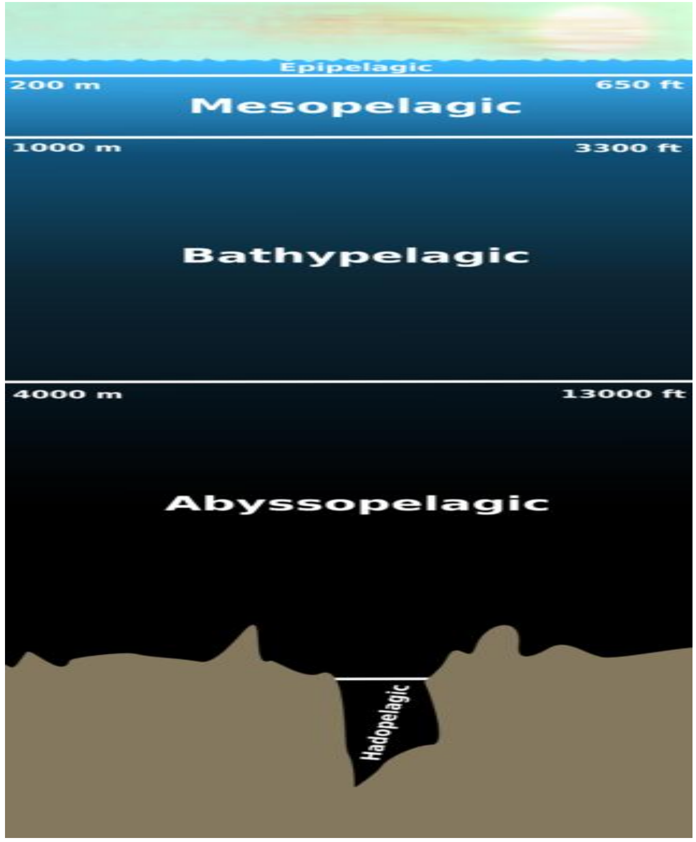

Fig.13. 9: Scale diagram of the layers of the pelagic zone

Deep sea is characterized by a set of environmental conditions, which in turn determine the adaptations of deep-sea forms. Of all the oceanic zones, light penetrates only into the euphotic zone; the remaining zones are aphotic or devoid of light (bathyal, abyssal and hadal zones). The term hadal zone is used to designate the perpetually cold and dark supreme depths of the ocean. It is characterized by high pressure, low temperature, absence of light, calmness of water, absence of phytoplankton and other producers, scarcity of food and resulting competition and soft bottom.

Apart from containing bacteria and perhaps fungi, the community of aphotic zones is characteristically animal. Because of lack of cues like light and temperature change, it was once thought that there was no seasonality in the deep sea, but this is not so. The amount of detritus coming into deeper waters depends on seasonal production cycles at the surface. Due to extreme pressure the bodies i deep-sea fish and other animals are very much compressed. Some bathypelagic fishes are economy' designs showing reduction of bony skeletons except for their jaws and contain watery muscles.

In some of them e.g., angler fish (*Melanocetus*) and gulper eel (*Eurypharynx*) the water content is very high, about 95%. Even without gas-filled swim bladders, they are near neutral buoyancy. Their hearts are very small, they have very little red muscle and low haematocrit values. Some deep-sea fishes exhibit greatly enlarged eyes or the so-called telescopic eyes, which are highly effective in visioning lights of very low intensity. In some deep-sea fishes the retina is composed of a number of tiers of rods, presumably arranged to absorb all the limited light that enters the eye. In some other deep-sea fishes, eyes are very small as they are of little apparent use, and still others are without eyes. Many deep-sea animals produce their own light by means of luminous organs, e.g., lantern fish. In anglerfish, the light is used as a bait to attract prey. Besides attracting and seeing the prey, luminescent display may also serve for species and sex recognition. Another interesting adaptation of deep-sea fish is the enormous mouth enabling them to swallow prey larger km themselves (e.g., the gulper, *Eurypharynx*, whale fish, *Cetomimus*). All benthic fishes lack pnm bladders and rest on the bottom, sometimes like tripod fishes (*Bathypterois* spp.) on stiff elongate fin rays. Correlated with soft substratum, many of the deep-sea animals have long appendages, abundant spines, stalks or other means of support, as illustrated by tripod fish, lampshells and crinoids. Perhaps these appendages are very useful in the darkness and serve for contact reception, or compensate for the difficulties of vision

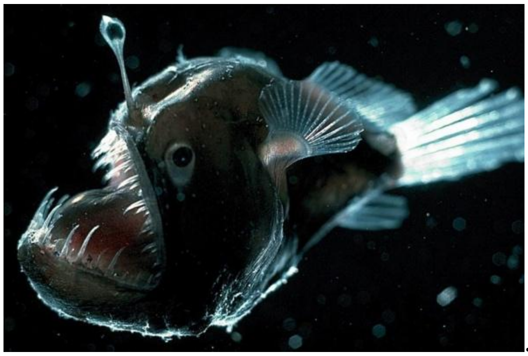.

Fig.13.10: Angler Fish (Courtesy: Wikipedia)

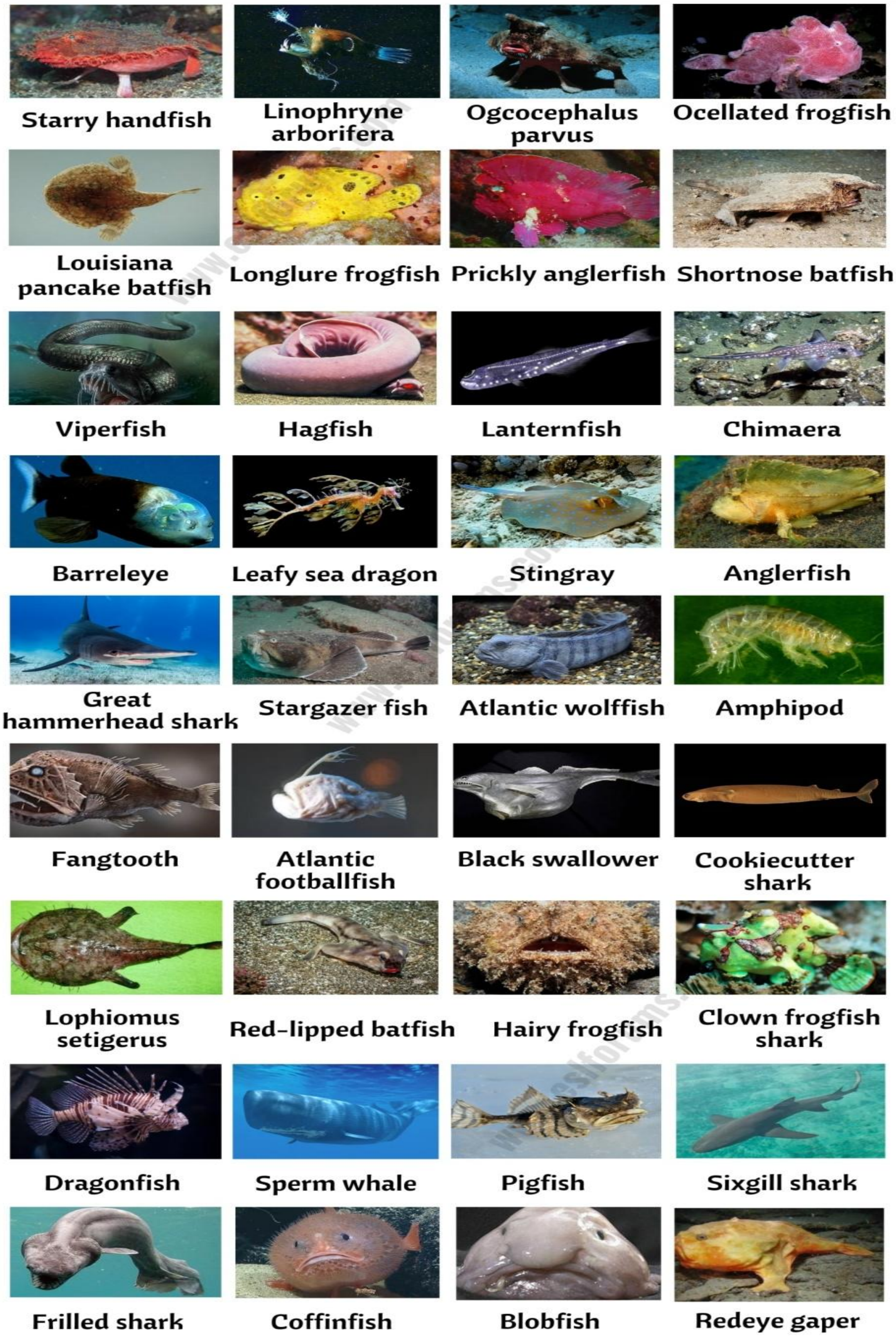

Fig. 13.11: Deep Sea Fish (Courtesy: www.eslforums.com)

13.6 HILL-STREAM AND CAVE-DWELLING FISHES

A number of fishes migrate from sluggish water of lower streams to colonize in the torrential waters of the upper streams. These migrations were chiefly in search of food and the shelters from the predators. In these new habitats fishes adapt to hill stream environment. Environmental conditions of the hill stream:

- **Strength of water currents:** It appears to be the primary factor in the evolution of hill stream fishes.The water moves predominantly in one direction in hills, causing both, the lesser stability of bottom materials as well as the erosion.
- **Light Intensity:** The sun rays in hill streams penetrate deep into water because it is shallow and very clear owing to absence of suspended particles. Fishes, therefore, have to adopt either to withstand the intense light or to shelter themselves under the rocks or stones.
- **Dissolved Oxygen:** The water is well aerated with plenty of oxygen due to rapid rate of flow of water. Abundance of oxygen is therefore, a favourable condition to fishes inhabiting the torrential streams
- **Temperature:** The temperature of hill streams fluctuates rapidly but remains more or less constant from surfaces to the bottom. The water is generally cooler but get heated by sun
- **Availability of Food:** Good amount of food is available in the hill stream but is in the form of algae covering stones and rocks. Fishes, therefore, have to largely depend upon the algal filaments. In certain regions the microbes and the insect's larva may also become available to the fishes.

The important fishes of hill stream belong to several genera of three families of order cypriniformes: *Balitoria, Barbus (Tor), Garra, Labeo, Schizothorax, Glyptothorax, Pseudochensis, Botia* etc.

Adaptive Modification in Hill Stream Fishes

Structural modifications which the hill stream fishes have developed to adapt to the environment are as follows:

1. **Shape:** Hill stream fishes are usually have flattened head and body in contrast to cylindrical bodies of fishes found in tanks and lakes. Example is *Balitoria*, their flattened

ventral surface permits no water to escape under them and so prevent them from being swept away with the fast water current. The head of hill stream fishes is generally semi-circular

2. **Size:** Hill stream fishes are generally small in size, have short and thicker bodies and semicircular heads. Their small size permits them to hide under the rocks & stones during the intense sunlight and prevents from being crushed under the rolling stones
3. **Scales and Bony Armour:** It is poorly developed. Absence of scales from ventral side also makes the ventral surface smooth for attachment on the rocky bottom
4. **Mouth:** Instead of being a transverse cleft at the anterior end of snout it is shifted towards the ventral side, behind the tip of snout.
5. **Barbels:** They are specialised, greatly reduced being short and stumpy as in *Balitora*
6. **Eyes:** They are usually small in size and are pushed toward the upper surface of head (protective measure against sunlight & to free the ventral surface for attachment) as in *Balitora, Glyptothorax, and Glptosternum.*

Fig.13.12: Balitora (Courtesy: Beta Mahatvaraj 2012)

Fig.13.13: Glptosternum (Courtesy: Academia)

7. **Fins:** fins are used as organs of locomotion & attachment. To perform dual function various modifications in structure of fins persists which are as follows:

- **Paired fins:** In *Garra*both pectoral pelvic fins are set low on the body to provide greater friction against rocks and stones. In *Astroblepuschoate* they forms sucker, which along with sectorial mouth is used to climb over vertical rocks and water fall. In many hill stream fishes, outer rays of paired fins are modified for adhesion, they become thick and flat.

Fig. 13.14: Astroblepuschoate climbs up the pitholes (Courtesy: PlanetCatfish.com)

- **Caudal Fin Andits Peduncle:** Hill stream fishes possesses a long, narrow, muscular band shaped caudal peduncle as in *Glptothoraxstraitus, Balitoria,* it is adaption for life at high altitudes and rapid flowing water. Lower lobe of caudal fin is long as compared to upper one as in *Glyptothorax, Garra, Balitoria*etc
- **Pectoral & Pelvic Fins:** These are also modified particularly in those species in which fins are used for adhesion. In *Glyptothorax and Pseudoecheneis* various bones of pectoral gill openingsgirdle are fused to provide strength. Keel like ridges are present on the ventral surface of the inter-clavicularbone, to provide surface for attachment to their muscles. The ridges are generally elevated posteriorly ending in spine like processes. Adductor and abductor muscles attached to the girdles are better developed, also have more four type of muscles are developed to move the spine,

8. **Breathing apparatus:** As the ventral surface is used for adhesion to rocks and stones, the gill slits lie on the sides and the gill chamber is specialised for retaining water for longer time. The restriction of the gill openings to the sides may effect respiration of fishes. But some factors helps in respiration. Firstly water in hills is well oxygenated. Secondly gill openings are small; the fish is able to retain water in the branchial chamber for longer

time. Thirdly the inner rays of the pectoral fins are kept in constant motion and helps in respiration by forcing the water in and out of the gill openings. The brancheostegal rays and membranes are greatly reduced in hill stream fishes

9. **Air bladder:** It is reduced or degenerate in these fishes, because the buoyancy would be disadvantage in swift currents.
10. **Adhesive devices:** One of the major problems of the fishes is to avoid being swept away in the rapid currents of mountain streams. For this the skin is variously modified to form adhesive organs. As in *Glyptosternum and Pseudoecheneis* bear a series of ridges on ventral surface of the body, which act as frictional devices? In*Erethistes*elongate, well developed striations are present on the chest and belly whereas genus *Laguvia,* striations are present on the chest only. In *Glyptothorax*, a well-developed U-shaped or V-shaped adhesive apparatus formed of folds of skin is present between the bases of pectoral fins. In *Garra,* the adhesive organ is in the form of disc behind the mouth

Fig.13.15: Glyptothorax showing adhesive pad (Courtesy: Wikipedia)

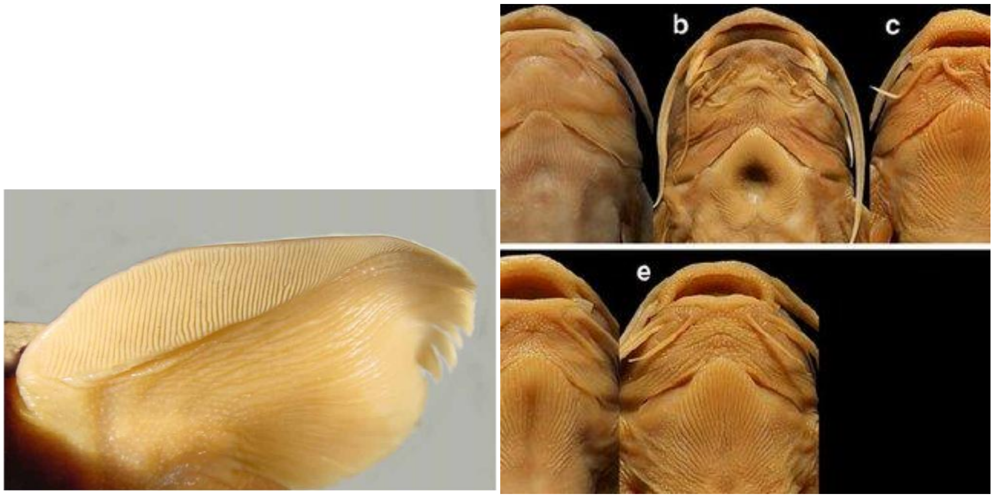

Fig.13.16: Adhesive organs on pectoral fin and Thoracic Adhesive Part (Courtesy: Researchgate.net)

CAVE DWELLING FISHES

Among the more extreme aquatic environments imaginable are underground water systems where no light penetrates and where food availability depends on infrequent replenishment from surface regions. However, cave living has advantages, including a scarcity of competitors and predators and a constant, relatively moderate climate. Fishes have evolved independently in caves around the world and, not surprisingly, similar adaptations to cave life have evolved repeatedly despite phylogenetic differences. The darkness, low productivity, and even high atmospheric pressure of cave environments have also led to some surprisingly strong convergences between cave and deepsea fishes. Caves usually develop in limestone formations (karst) because of the solubility of carbonaceous rock, although caves exist in other rock types such as lava tubes on volcanic slopes. Caves include places where water dives underground and resurfaces after a short distance, or where springs upwell near the surface and are illuminated by dim but daily fluctuating daylight (technically a cavern). The classic cave environment is a continually dark, subterranean system where fluctuations in temperature, oxygen, and energy availability are minimal and where little interchange occurs with other areas. The biota of caves are especially interesting because a continuum of habitats exists between the surface, caverns, and deep caves. We can consequently often identify closely related and even ancestral organisms from which cave populations and species evolved. This allows comparison of cave and surface forms and analysis of the processes and selection pressures that have produced cave adaptations. Approximately 136 species and 19 families in 10 different orders of teleostean fishes have colonized caves. These unusual fishes – termed variously hypogean, troglobitic, phreatic, and stygobitic – occur in scattered locales at tropical and warm temperate latitudes on all continents except Antarctica and Europe. With the exception of some bythitid cusk-eels and gobies, the families are restricted to fresh water. Most cave fishes are ostariophysans (characins, loaches, minnows, and eight catfish families), which is not surprising given the overwhelming success of this superorder in freshwater habitats. The remaining four families are either paracanthopterygian (ambloypsid cavefishes) or acanthopterygian (poeciliid livebearers, synbranchid swamp eels, and cottid sculpins). Only one family, the amblyopsid cavefishes, consists primarily (four of six species) of cave-dwelling forms.

ADAPTATION

Typical cave-adapted fishes are characterized by a lack of pigmentation, reduced squamation, a reduction or loss of light receptors (involving eyes and the pineal gland), greatly expanded lateral line and external chemo-sensory receptors, and relative decreases versus increases in brain areas associated with vision versus hearing and chemoreception, respectively. Behaviors typically mediated by vision are lost, such as schooling, the dorsal light reaction, and circadian rhythms.

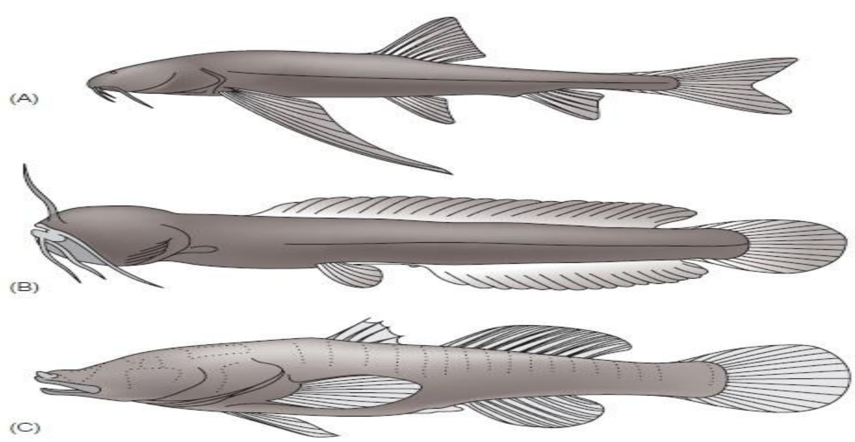

Fig. 17: Cave fishes from three different orders, showing convergent loss of eyes, among other oddities. (A) A balitorid river loach, Triplophysa xiangxiensis (Cypriniformes), from China. (B) A clariid catfish, Horaglanis krishnai (Siluriformes), from India. (C) An eleotrid sleeper, Typhleotris madagascariensis (Perciformes), from Madagascar

Taste buds in surface-dwelling *Astyanax fasciatus*, a characin, are generally restricted to the mouth region, whereas in cave-adapted populations of the same species they cover the lower jaw and ventral areas of the head. Chemosensory capabilities are better in cave forms; caveadapted *A. fasciatus* are about four times more effective in finding meat on the bottom of a darkened aquarium than are the surface forms. Adaptations to unpredictable or irregularly occurring food supplies also exist. When fed ad libitum (as much as they can consume), cave Astyanax build up larger fat reserves than surface forms, again by a factor of four (37% of body mass vs. 9%). Parallel comparisons can be made within the family of cavefishes (Amblyopsidae). The cave genera (*Amblyopsi*s, *Typhlichthys, and Speoplatyrhinus*) swim more efficiently, have lower metabolic rates, and find prey quicker and at greater distances in the dark than surface forms (Chologaster). The cave forms are also better at avoiding obstacles and at memorizing the locations of objects than are the surface fish. Cave catfishes (blindcats) in the North American family Ictaluridae show parallel changes with respect to eye loss, absence of pigmentation, pineal reduction, enlarged lateral line pores and canals, and brain modifications. Many analogous adaptations have also been observed in other cave-adapted taxa, including beetles, amphipods, crickets, crayfishes, shrimps, and salamanders. Adjustments to cave existence also occur in the reproductive biology and life history traits of cave-dwelling fishes. Not surprisingly, visual displays are generally lacking during courtship of cave species, even in taxa such as livebearers and characins where they occur commonly in surface forms. With respect to life history traits, cave-adapted amblyopsids produce fewer but larger eggs with greater yolk supplies, have larvae that spend more time before hatching, and have a later age at maturation and longer life spans. Reproductive rates of cave populations are surprisingly low. Only about 10% of the mature fish in a population of cavefishes may breed in any one year, each female producing 40–60 large eggs. These eggs are incubated in the mother’s gill cavity for 4–5 months, long after the young are free-swimming. This may be the longest period of parental care for an externally fertilized fish species. Many of these characteristics are what one would expect in a habitat where adult mortality and interspecific competition are low, environmental conditions stable, and food scarce. The degree of anatomical and behavioral change in a cave population is often correlated with the length of time available since the cave was colonized. Eye loss, characteristic of cave-adapted forms, shows some responsiveness to light availability. When youngAstyanax fasciatus from caves of different presumed ages are raised in the presence of light, individuals from old cave populations do not develop eyes, surface populations develop eyes, and populations thought to have invaded caves more recently vary in eye size. Food sources in caves are rather limited. Since no photosynthesis can occur in the sunless cave environment, food can only arrive if brought in by other animals or carried in by percolation through the rock or by water currents, such as during occasional floods. Common food types differ among families, but bat and cricket guano, bacteria, algae, small invertebrates (isopods, amphipods, copepods), and conspecifics are the common food types of most groups. In Mexican caves containing the livebearer *Poecilia mexicana*, bat guano is supplemented by bacteria associated with sulfur springs in the cave, an interesting analog to deepsea vent communities. Cave fishes respond to chemical or mechanical cues given off by the food; a clay ball dropped into the water containing cave fishes will induce active swimming and searching by fish within 1 m of the ball. Cave fishes usually live at low densities, particularly those in isolated deep caves; most populations involve hundreds or at most thousands of individuals. Population density is strongly correlated with food availability, which again correlates with degree of isolation. Typical population densities of such fishes as the amblyopsid cavefishes are low, ranging from 0.005 to 0.15 fish/m^2. The Blind Cavefish, *Astyanax fasciatus*, can reach densities of 15/m^2 and Poecilia mexicana can reach densities of 200/m^2 where sulfur springs occur, and near-surface caves that contain bats as an energy source host even higher densities of cavedwelling fishes.

13.7 SUMMARY

Adaptation is an important survival skill in all species.Adaptationsare changes an organism undergoes to fit different surroundings. If an organism is not able to evolve over time to suit its environment it may eventually become extinct. The natural surroundings in which an animal or plant is adapted to live is called its habitat.When ahabitat changes the species that is able to adapt best is most likely to survive. Fish, like other animals, have also adapted to live in different types of habitats. Most physical adaptations in fish occur in the mouth, body shape, coloration or method of reproduction. Various adaptations in these areas help fish survive in their habitats. Fish that forage on insects in streams have a much different mouth structure than fish that feed on other fish. The walleye, for example, has a large jaw with strong teeth to help it catch its food. Some fish have no teeth, only round vacuum-like mouths, these fish suck up organic material from the bottom or a stream or river. Body shape is also an important adaptation in fish. Fast moving fish have long torpedo shaped bodies to help them move though the water. Other fish that stay at the bottom of a stream or river have longer flat bodies. Most fish have fins; the location and shape of these fins vary from species to species. In general fish have a dorsal fin on their back and pelvic and anal fins on their undersides. They also have pectoral fins near the gills and a caudal fin as the tail. These fins can be prominent parts of the body structure or they can be, as in the case of the eel, practically unnoticeable. The size and texture of the scales also varies from fish to fish. Some, such as carp have large, noticeable scales; other fish have small scales, which are embedded in the skin giving the fish a smooth feeling. Another adaptation in fish, and probably one of the most noticeable, is the skin coloration. A fishes coloration can help it adapt to its' environment but the environment can also affect the skin color making it brighter or duller. Coloration can also be used as camouflage to help the fish hide from predators. For example, some fish such as pickerels and blue gills have vertical stripes to help them hide in vegetation. In some species, the male and female have different markings. Variation of patterns on the skin can be used to identify different sexes.

Some marine fish have the ability to produce light through bioluminescence. Most light-producing fish live in mid-water or are bottom-dwelling deep sea species. In fish, bioluminescence can occur two different ways: through symbiotic bacteria living on the fish or through self-luminous cells called photophores. Some species of deep sea angler fish (Lophiiformes) may use this light to attract prey, while others, like the Atlantic midshipman (*Porichthys plectrodon*), may use this light to attract mates. Many fish may use venom as a form of defense. Most venomous fish deliver the toxins through the use of a spine. Venomous spines are found in a wide variety of fish including stingrays, chimaeras, scorpionfishes, catfishes, toadfishes, rabbit fishes, and stargazers. Venomous spines can have poison glands along the grove of the spine, as with stingrays, or at the base of the spine, as in some catfish. While humans can be stung by a multitude of fishes, few species are life-threatening.

Elasmobranchs (sharks, skates, and rays) possess an electric sense system known as the ampullae of Lorenzini. This system consists of many tiny gel-filled canals positioned on the head of the fish. Through this system these fishes are able to detect the weak electric fields produced by prey. It is also believed that these fish can use this sense to detect the electric fields they induce when swimming through the earth's magnetic field, as a sort of compass. Since the fishes are able to generate the fields they detect, this is a form of active electro-orientation.

Some species of skates and rays also have electricity-producing organs. The electric rays have paired electric organs located on either side of the head, behind the eyes. With these organs, electric rays are able to shock and stun their prey. The skate's electric organs are located near the tail. However, these electric organs only produce weak electric fields not capable of stunning prey. Researchers believe that the skate's electric organs are used for communication and mate location. The electric eel can also produce electric fields. These eels use weak electric fields for navigation, prey location, and communication. Additionally, these eels can produce strong electric fields to stun potential prey. The strength of the "shock" is related to the size of the eel, with larger individuals being able to produce more of a "shock."

13.8 TERMINAL QUESTIONS AND ANSWERS

Q1. Describe colouration, its control and significance in fishes.

Q2. Discuss the hill stream adaptation in fishes.

Q3. Define the Weberian apparatus and describe its structure and function.

Q4. Explain the bioluminescence organs of fisshes and write its significance.

Q5. Write a note on electricity generating organs in *Torpedo*.

Q6. Write a short note on cave-dwelling fishes.

Q7. Give a detailed account on deep sea adaptations.

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